LUMBER SEASONING

PREPARED BY THE FOREST PRODUCTS LABORATORY

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PREFACE

This publication deals with the seasoning of lumber, especially by comparatively simple means applicable throughout the entire world. Seasoning is important because the removal of moisture from green wood is generally necessary before the material can be safely stored or used to best advantage. For particular uses, drying to a low moisture content is required.

While the main part of this manual refers to methods and techniques of air-drying and kiln-drying lumber, other phases are covered, such as basic properties of wood, principles of moisture removal, protection of green wood from attack by fungi and insects, and dry lumber storage.

This publication was prepared for the International Cooperation Administration (now the Agency for International Development) by Edward C. Peck and John M. McMillen of the Forest Products Laboratory, Forest Service, U.S. Department of Agriculture. Each is a forest products technologist with extensive experience in seasoning wood.

Mention of the name of any firm, product, or process in this publication is not to be considered a recommendation or endorsement by the U.S. Department of Agriculture, but merely a citation of an example that is typical in its field.

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INTRODUCTION

Live trees standing in the forest contain tremendous quantities of water. When the trees are cut, the wood begins to lose this moisture. In fact, for most uses to which wood is put, almost all of the water must be removed. The process of getting this water out of the wood is called seasoning.

During the removal of this water, the wood can undergo undesirable changes in color, insects or stain and decay fungi can attack it, or shrinkage can cause defects such as checking and warping. The object of any good seasoning process is to remove the water as economically as possible without causing excessive deterioration.

Seasoning can be done by natural air drying, by kiln drying in heated and humidified air, or by other special methods. Air drying can bring the wood to a final moisture content suitable for temporary storage or shipment, for exterior use, or for interior use where there is little additional heating. It is generally a slow method of drying.

Wood that has been air dried can be brought to lower moisture content values by storage in a slightly heated room or shed; this will dry it enough for some uses in heated buildings. For faster and better quality drying, a dry kiln should be used so there can be close control of drying conditions. In a kiln, higher temperature and fast air circulation speed the drying while humidity is controlled to prevent shrinkage defects. Humidity also can relieve stresses and set in the lumber at the end of drying, so that the boards will not warp when they are resawed or machined to smaller sizes or irregular shapes.

This publication is intended to help people who are seasoning lumber with comparatively simple equipment. The methods described are applicable throughout the world. Major emphasis is placed on the use of manpower. Some operations require simple machines to supplement manpower and others will require fuel, usually employing those portions of trees that do not go into sawed or other wood products. The text deals with properties of wood related to drying, moisture content of wood for various uses, methods of protecting green or freshly cut logs and lumber from attack by organisms, handling and transporting the material, and air drying, predrying, kiln drying, and storage of the dried lumber. Predrying is an accelerated air-drying process that may be of particular interest to producers of lumber for export. No attempt is made to discuss the high-temperature kiln drying used in Europe or other special methods of drying. These processes, although faster than kiln drying, are not more economical, and they are not suitable for general use.

Relative costs of drying by the various methods depends on a great number of factors that will differ from country to country. Air drying is probably the cheapest method of drying. If it is done in a crowded area where the land has even a moderate rental value and protective measures and insurance against fire are required, costs can be considerable. Predrying costs are about the same in the United States as air drying costs, but a building and fan equipment are involved. Predrying can produce better quality lumber than air drying under some conditions.

Kiln drying in small modern units may be considered up to four times as expensive as air drying. In more primitive equipment or in large modern kilns, it may be no more than twice as expensive as air drying. It is, of course, capable of doing a better and more complete drying job.

Much of the work involved in seasoning lumber can be done by ordinary labor. There are many details involved in following good practice, however. Unless careful attention is paid to these details, considerable damage can occur to valuable lumber. The seasoning job, therefore, merits good supervision and the training of operating personnel so that they can do their jobs correctly and take considerable pride in their work.

Supplementing the general information contained here, the Appendixes list specific details that may be helpful in operations in a particular country. Appendix A lists selected reference material. Appendix B gives costs of equipment, manpower, and other items in relation to air drying, predrying, and kiln drying in the United States. Appendixes C and D give a partial list of United States suppliers of end coatings and toxic dips. A partial list of manufacturers of dry kilns, engineers, and accessory suppliers in the United States is given in Appendix E, and a suggested bill of materials for a small hot air kiln is covered in Appendix F. Appendix G shows an exact method of calculating wood shrinkage or swelling with changes in moisture content. Scales for converting from some commonly used English systems of measurement to metric units are given in Appendix H.

PROPERTIES OF WOOD RELATED TO DRYING

The structural features, the physical properties, and even some strength properties of the wood cut from trees of various species have important effects on the drying characteristics. Specific gravity, structure, extractives, tree growth characteristics, shrinkage, and the ease with which moisture moves all affect the speed of drying and the development of drying defects. The good seasoning supervisor, therefore, should have a good general knowledge of all of these properties. He should also have a detailed knowledge of basic wood-moisture relations, methods of determining moisture content, and the characteristics of wood that bear on drying rates and defects. He also should know how to use the tables of wood moisture content and shrinkage and how to calculate the changes in dimension when wood goes from one moisture content to another.

WOOD STRUCTURE

Hardwoods and Softwoods

All species of trees are grouped into two classes -- hardwoods, which have broad leaves, and softwoods, which have needle-like leaves as in pine or scale-like leaves as in cedars. The terms do not apply to the actual hardness or softness of the woods, for some pines have harder wood than such hardwoods as basswood. The hardwoods belong to a class of plants known as Angiosperms and the softwoods belong to the Gymnosperms. The structure of hardwoods is more complex than that of softwoods, and thus different drying procedures may be required for the two classes.

Bark, Wood, and Pith

A cross section of a tree trunk (Figure 1) shows certain well-defined features from the outside to the center: the bark; a light-colored layer of wood called sapwood; and an inner zone of wood, usually darker than the sapwood, called heartwood. In the structural center of the log is a small soft core known as the pith.

Figure 1.--Cross section of an oak tree. A is the microscopic cambium or growth layer; B, inner bark; C, outer bark; D, sapwood; E, heartwood; F, pith; and G, wood rays.

Both the wood and the bark are composed of small structural units called cells. Between the bark and the wood is a layer of thin-walled living cells, invisible without a microscope, called the cambium. In this layer, all growth in thickness of bark and wood has taken place by cell division.

Sapwood and Heartwood

In the living tree, a relatively few living cells are located just under the cambium and in the wood rays of the sapwood. The whole sapwood usually is very permeable and serves in the movement of sap upward in the tree. The cells of the heartwood are dead, and the principal function of heartwood is to supply strength to the trunk.

As the tree increases in diameter by the addition of new layers of sapwood under the bark, the zone of heartwood also enlarges. As the cells of the sapwood change to heartwood, they are infiltrated by materials that reduce permeability and often give the wood a darker color. The circumference of the heartwood may be irregular, and does not necessarily follow the growth rings.

The relative amounts of sapwood and heartwood vary considerably, both between species and in logs of the same species. A tree of small diameter has more sapwood proportionately than a similar tree of larger diameter. Within a species, sapwood is thickest in the most vigorously growing trees. Heartwood and sapwood are equal in strength.

After the timber is cut, the heartwood in most species is more resistant to the attack of decay, stain, and insects than is the sapwood. The decay resistance of heartwood is due to the infiltrated materials, many of which are toxic to fungi. In some species the heartwood is not much superior to the sapwood with respect to decay resistance. In the living tree, however, the sapwood is usually less subject to attack, whereas specific fungi often attack the heartwood.

Heartwood is, as a rule, less permeable than sapwood to liquids. For this reason, heartwood dries more slowly than sapwood and often requires different drying methods. It is also more difficult to treat with preservatives. In resinous woods, the heartwood usually contains more resin than the sapwood.

Growth Rings

A cross section of a log grown in a temperate climate or where there are definite growing seasons often shows well-defined concentric layers of wood. These layers are called growth rings and, where they correspond to yearly increments of growth, may be called annual rings. The inner part of the ring, which is formed during the early part of each growing season, is known as springwood or early wood. The outer part is formed later in season and is termed summerwood or late wood. The cells of the springwood are generally larger and thinner walled than those of the summerwood; consequently, springwood is softer, weaker, and generally lighter in color. Where there are no distinct growing seasons, there are no growth rings, and the wood appears to have a homogeneous structure.

When lumber is cut from a log, the growth rings are cut across in one direction or another and form a pattern on the broad faces of the boards. Quartersawed and plainsawed boards cut from a hardwood log are shown in Figure 2.

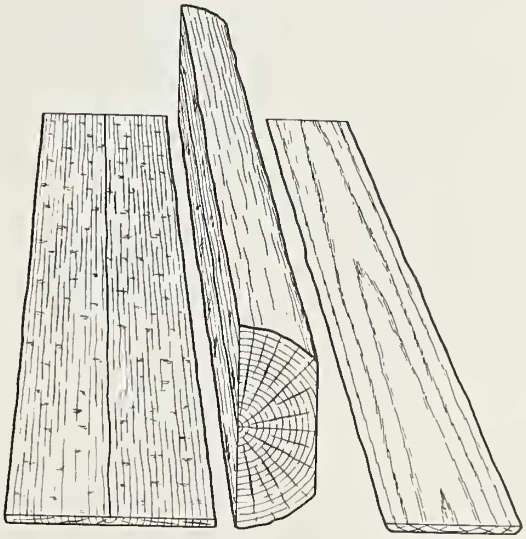

Figure 2. --Quartersawed board (left) and plainsawed board (right) as cut from a log.

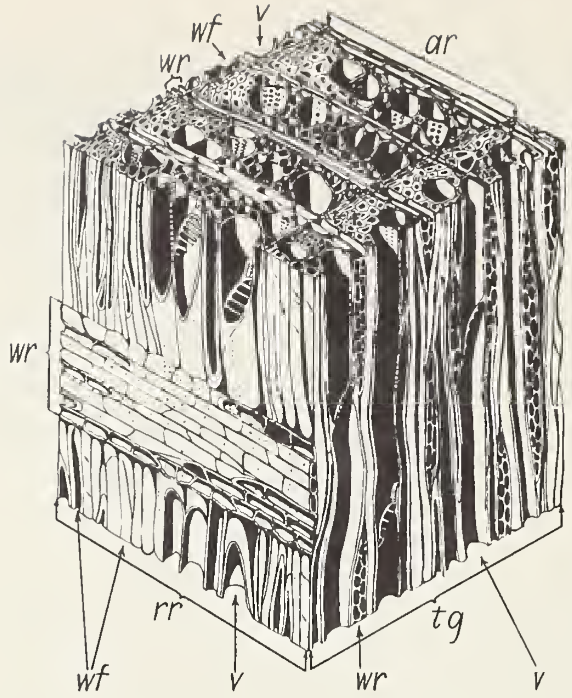

Figure 3. --Drawing of a section of a hardwood highly magnified: wood fibers (wf), vessels (v), and cells shown on radial surface (rr); tangential surface (tg); and in wood rays (wr); also growth ring (ar).

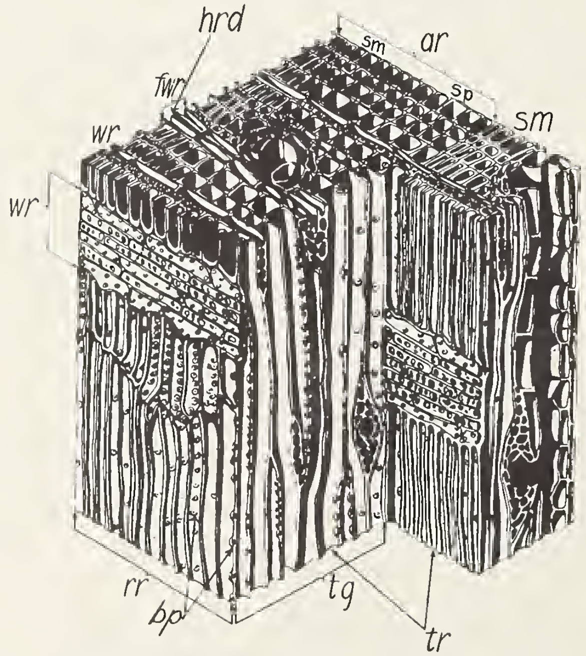

Figure 4. --Drawing of a section of a softwood highly magnified: fibers or tracheids (tr); ray cells (wr, fwr); and horizontal resin ducts (hrd) shown on radial surface (rr) and tangential surface (tg). Also annual ring (ar), springwood (sp), summerwood (sm), and bordered pits (bp).

Cellular Structure

The cells of the wood vary in size and shape but many are long hollow, and pointed at the ends. These cells are customarily called fibers or tracheids. Large-diameter cells, or vessels, are also found in hardwoods. Still other cells, in the wood rays of both hardwoods and softwoods, lie on radial lines from the pith to the bark. Figure 3 shows the pores and other cells in a hardwood cube highly magnified. Figure 4 shows a similar cube of softwood. Many hardwoods contain relatively large wood rays, while some softwoods contain resin ducts. Both of these are related to susceptibility to surface checking during drying.

Grain

This term is often used to indicate the general direction of the fibers in wood or lumber. The wood fibers in a tree trunk are usually approximately parallel to its axis. Therefore, three grain directions are commonly considered. The longitudinal direction is along the length of the fibers, or parallel to the axis of the tree. The radial direction is parallel to a radius of the tree from the pith to the bark (Figure 1). The tangential direction is parallel to the growth rings.

Lumber has its greatest strength when it is straight-grained, that is, when the fibers are parallel to the long axis of the piece. When the fibers lie at an angle to the axis of the tree trunk, this results in spiral grain (Figure 5). Several times during the life of a tree the direction of the spiral may be

Figure 5.--Spiral grain (left) and straight grain (right) indicated by the direction of seasoning checks in dead tree trunks.

reversed, resulting in interlocked grain. Quartersawed boards cut from such a tree will exhibit a ribboned effect. Another type of cross grain is produced when a log is sawed at an angle with the bark instead of parallel to it. Crooked and knotty logs also yield boards that contain cross grain. All types of cross grain cause mechanical weakness and drying defects. Warping is the principal drying defect resulting from cross grain.

Knots

A knot is a portion of a branch or limb that has been overgrown by other wood in a tree. Normally a knot starts at the pith and increases in diameter from the pith outward as long as the limb is alive. Occasionally, knots start at some distance from the pith. The shape or appearance of a knot on a sawed face depends upon the direction in which it has been cut in the process of lumber manufacture.

Knots frequently appear round or oval, but a spike knot will result if the knot is cut approximately parallel to its long axis. An intergrown knot results from the fact that, so long as a limb remains alive, its fibers interlace with those of the tree trunk. After the death of a limb, at some intermediate stage of the tree's growth, the wood formed in the tree trunk makes no further connection with the knot, but grows around it. This produces a dead or encased knot, which may be loose or held in position by resins when the trunk is sawed into lumber. After a dead limb breaks off, the distortion of grain in successive layers of wood becomes less and less with increasing growth, and finally clear, straight-grained wood is produced.

The distortion and discontinuity of the grain around knots weaken the wood and cause irregular shrinkage and warping. When lumber dries, the knots and the wood adjacent to them tend to check. The knots also may become loose because of the shrinkage of both the knots and the wood.

Juvenile Wood

The wood in the first few rings adjacent to the pith is often referred to as juvenile wood. This type of structure sometimes has greater-than-normal shrinkage along the grain that may contribute to warping if it is located on a face or edge of a board (Figure 6). Juvenile wood is most serious when there are relatively wide early growth rings followed by narrower ones.

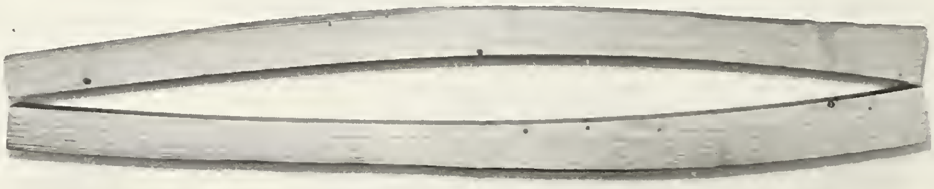

Figure 6. --Warp that may result when juvenile wood is located on the edge of lumber is shown in these 2 by 4's.

Reaction Wood

Compression wood. --In softwood species compression wood is an abnormal type of wood that occurs on the underside of leaning trees. Compression wood may also be present in trees that are now vertical but previously had leaned. Compression wood usually shows growth rings that are wider than the adjacent normal rings and unusually wide summerwood bands. Summerwood in compression wood does not appear as dense, dark colored, or hornlike as normal summerwood. This resulting lack of contrast of summerwood with springwood gives a lifeless appearance to compression wood. Compression wood is usually yellowish in color when dry and may also show a reddish tinge when green. Streaks of compression wood frequently are interspersed with normal wood. Compression wood shrinks excessively along the grain; thus it may develop cross breaks during drying or cause warping (Figure 7).

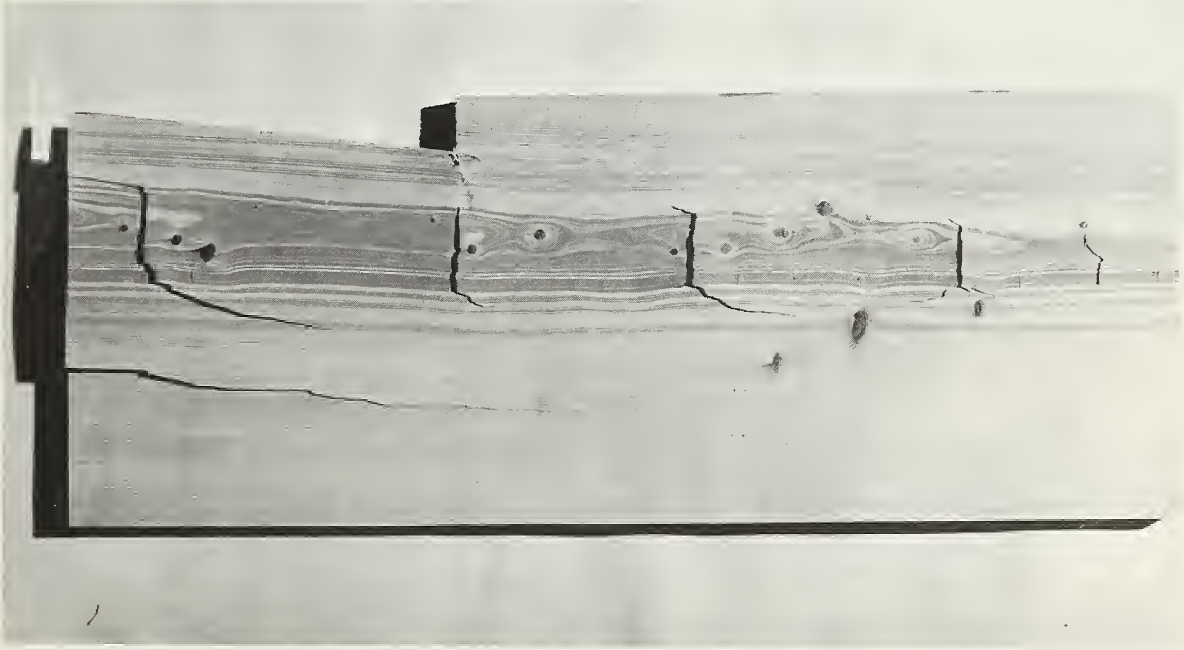

Figure 7. --Cross breaks resulting from longitudinal shrinkage of compression wood (dark streak) in a softwood.

Tension wood. --Tension wood is an abnormal type of wood that occurs in hardwoods. It occurs on the upper side of leaning trees, but may also occur in trees that once leaned but are now straight. When tension wood is present, surfaces usually show projecting fibers and planed surfaces often are torn or with raised grain (Figure 8). Tension wood also possesses abnormal shrinkage along the grain, and thus may contribute to warping during drying.

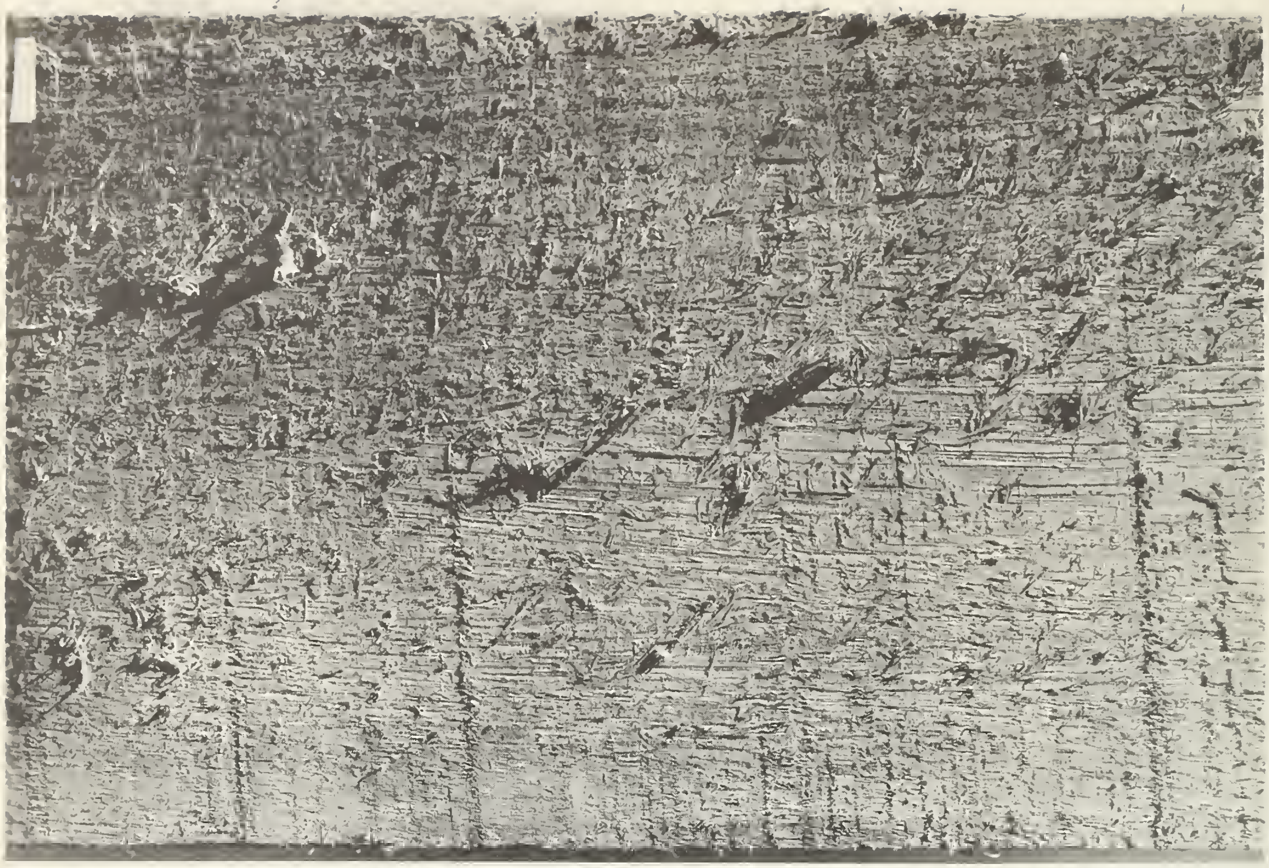

Figure 8.--Projecting fibers of tension wood on a sawed surface of a mahogany board.

WOOD-MOISTURE RELATIONS

Amount and Location of Water in Wood

Freshly cut lumber contains considerable moisture, often called sap. Sap is composed primarily of water, with usually small amounts of other materials in solution. This water exists in the wood in two forms: (1) as bulk liquid contained in the cell cavities, known as free water, and (2) as absorbed or bound water held within the cell walls. Sapwood usually contains more moisture than heartwood, particularly in softwoods. The water in freshly cut or green lumber may weigh more than the dry wood substance, but usually it weighs less. Table 1 gives moisture content values for green wood of numerous species, most of which are native to the United States.

The amount of moisture in wood is expressed as a percentage of the weight of the ovendry wood. The ovendry weight of the wood is determined by exposing wood in an oven to a temperature of 214° to 221°F. until a constant weight is attained. Of the amount of water contained in green wood, approximately 30 percent is adsorbed or bound within the cell walls, and the remainder is free water. This value, 30 percent moisture content, is called

Table 1.--Moisture content of some North American woods in the green condition[1]

Species		Moisture Content		
Botanical name	Common name[2]	Heartwood	Sapwood	Mixed heartwood and sapwood
		Percent	Percent	Percent
	HARDWOODS			
Acer saccharinum	Maple, silver	58	97	------
Acer saccharum	Maple, sugar	65	72	------
Aesculus octandra	Buckeye, yellow	------	------	141
Alnus rubra	Alder, red	------	97	------
Betula alleghaniensis	Birch, yellow	74	72	------
Betula papyrifera	Birch, paper	89	72	------
Carya aquatica	Hickory, water	97	62	------
Carya glabra	Hickory, pignut	71	49	------
Castanea dentata	Chestnut	120	------	------
Celtis occidentalis	Hackberry	61	65	------
Cornus florida	Dogwood, flowering	------	------	62
Diospyros virginiana	Persimmon	------	------	58
Fagus grandifolia	Beech	55	72	------
Fraxinus americana	Ash, white	46	44	------
Ilex opaca	Holly, American	------	------	82
Juglans nigra	Walnut, black	90	73	------
Liquidambar styraciflua	Sweetgum	79	137	------
Liriodendron tulipifera	Yellow-poplar	83	106	------
Magnolia sp.	Magnolia	80	104	------
Nyssa aquatica	Tupelo, water	150	116	------
Nyssa sylvatica	Tupelo, black	87	115	------
Ostrya virginiana	Hophornbeam, eastern	------	------	52
Platanus occidentalis	Sycamore, American	114	130	------
Populus deltoides	Cottonwood, eastern	------	------	125
Populus tremuloides, P. grandidentata[3]	Aspen	95	113	------
Prunus serotina	Cherry, black	58	------	------
Quercus alba	Oak, white	65	81	------
Quercus falcata	Oak, southern red	83	75	------
Quercus rubra	Oak, northern red	80	69	------
Robinia pseudoacacia	Locust, black	------	------	40
Salix nigra	Willow, black	------	------	139
Tilia americana	Basswood	81	133	------

See footnotes at end of table.

Table 1.--Moisture content of some North American woods in the green condition[1]--Continued

Species		Moisture content		
Botanical name	Common name[2]	Heartwood	Sapwood	Mixed heartwood and sapwood
		Percent	Percent	Percent
	HARDWOODS--Continued			
Ulmus americana	Elm, American	95	92	------
Ulmus thomasii	Elm, rock	44	57	------
	SOFTWOODS			
Abies amabilis	Fir, Pacific silver	55	164	------
Abies concolor	Fir, white	98	160	------
Abies grandis	Fir, grand	91	136	------
Abies procera	Fir, noble	34	115	------
Chamaecyparis lawsoniana	Port-Orford-cedar	50	98	------
Chamaecyparis nootkatensis	Alaska-cedar	32	166	------
Juniperus virginiana	Redcedar, Eastern	33	------	------
Larix occidentalis	Larch, Western	54	119	------
Libocedrus decurrens	Incense-cedar	40	213	------
Picea glauca, P. mariana P. rubens[3]	Spruce, eastern	34	128	------
Picea sitchensis	Spruce, Sitka	41	142	------
Pinus contorta	Pine, lodgepole	41	120	------
Pinus echinata	Pine, shortleaf	32	122	------
Pinus lambertiana	Pine, sugar	98	219	------
Pinus monticola	Pine, western white	62	148	------
Pinus palustris	Pine, longleaf	31	106	------
Pinus ponderosa	Pine, ponderosa	40	148	------
Pinus strobus	Pine, eastern white	------	------	68
Pinus taeda	Pine, loblolly	33	110	------
Pseudotsuga menziesii	Douglas-fir, Coast	37	115	------
	Douglas-fir, Rocky Mountain	30	112	------
Sequoia sempervirens	Redwood	86	210	------
Taxodium distichum	Baldcypress	121	171	------
Thuja plicata	Redcedar, Western	58	249	------
Tsuga canadensis	Hemlock, eastern	97	119	------
Tsuga heterophylla	Hemlock, western	85	170	------

[1] Data from "Wood Handbook" (Appendix A).
[2] From "Check List of Native and Naturalized Trees of the United States" (Appendix A).
[3] Mixture.

the fiber saturation point. At this point the cell walls are completely saturated but the cell cavities are empty. Although there are some variations by species, this value is a good approximation for all species. The fiber saturation point is significant from the standpoint of mechanical, physical, and some electrical properties.

Wood is a hygroscopic material and has the ability to take on and give off moisture in the form of vapor. In general, wet wood gives up water vapor to the atmosphere. Dry wood takes water vapor from a humid atmosphere. Because of this hygroscopic property, wood tends to reach a moisture content in balance with the relative humidity and temperature of the surrounding air. This is called the equilibrium moisture content, often abbreviated EMC. Wood at the fiber saturation point or above is in approximate equilibrium with air at 100 percent relative humidity, or saturated air; wood at 0 percent moisture content is in equilibrium with air at 0 percent relative humidity. Table 2 gives equilibrium moisture content values for wood at different dry-bulb temperatures and wet-bulb depressions and relative humidities. Tropical woods may have somewhat different equilibrium moisture content and fiber saturation point values, especially the woods with large amounts of extractives (data in Pennsylvania State College Forestry School Bulletin 598, referenced in Appendix A).

Moisture Content Determination

The moisture content of wood may be determined by the ovendrying method or by use of electric moisture meters. The ovendrying method is the standard method, and it is accurate throughout the whole range of moisture content. It requires that a cross section be cut from the material being tested. It also requires ovendrying the section very carefully for at least 12 hours. Electric moisture meters permit the determination of moisture content without cutting or mutilating the board. They are very rapid and simple to use, but they are accurate from only about 7 to 25 percent moisture content. With some types of meters, small holes are made in the lumber that is tested.

Ovendrying method.--The ovendrying method consists of the following steps:

(1) Select a representative board and cut a cross section about 1 inch thick along the grain.

(2) Immediately after sawing, remove all loose splinters and weigh the section.

(3) Put the section in an oven maintained at a temperature of 214° to 221°F. and dry until a constant weight is attained.

(4) Weigh the section to obtain the ovendry weight.

(5) Subtract the ovendry weight from the initial weight, divide the result by the ovendry weight, then multiply the result by 100 to obtain the percentage of moisture in the original board:

Table 2. --Relative humidity and equilibrium moisture content of North American woods for various dry-bulb temperatures and wet-bulb depressions [1]

Dry-bulb temperature		Wet-bulb depression (°F.)																					
°F.		2	3	4	5	6	7	8	9	10	11	12	13	14	15	17	20	25	30	35	40	45	50
40	R.H.	83	75	68	60	52	45	37	29	22	15	8	----	----	----	----	----	----	----	----	----	----	----
	EMC	18	15	13	11	10	9	7	6	5	3½	2	----	----	----	----	----	----	----	----	----	----	----
55	R.H.	88	82	76	70	65	60	54	49	44	39	34	28	24	19	9	----	----	----	----	----	----	----
	EMC	20	17	15	13½	12	11	10	9	8½	7½	7	6	5	4½	2½	----	----	----	----	----	----	----
70	R.H.	90	86	81	77	72	68	64	59	55	51	48	44	40	36	29	19	3	----	----	----	----	----
	EMC	21	18	16½	15	14	12½	12	11	10	9½	9	8½	8	7	6	4	1	----	----	----	----	----
85	R.H.	92	88	84	80	76	73	70	66	63	59	56	53	50	47	41	33	20	9	----	----	----	----
	EMC	21	19	17	16	14½	13½	12½	12	11	10½	10	9½	8½	8½	8	6	4	2	----	----	----	----
100	R.H.	93	89	86	83	80	77	73	70	68	65	62	59	56	54	49	41	30	21	12	4	----	----
	EMC	21	19	17½	16	15	14	13	12½	12	11	10½	10	9½	9	8½	7	6	4	3	1	----	----
110	R.H.	93	90	87	84	81	78	75	73	70	67	65	62	60	57	52	46	36	26	18	11	4	----
	EMC	21	19	17½	16	15	14	13	12½	12	11½	11	10½	10	9½	9	8	6	5	4	2½	1	----
120	R.H.	94	91	88	85	82	80	77	74	72	69	67	65	62	60	55	49	40	31	24	17	10	5
	EMC	21	19	17	16	15	14	13½	13	12	11½	11	10½	10	9½	9	8	6½	5½	4½	3	2	1
130	R.H.	94	91	89	86	83	81	78	76	73	71	69	67	64	62	58	52	43	35	28	21	15	10
	EMC	21	19	17	16	15	14	13½	13	12	11½	11	10½	10	9½	9	8	7	6	5	4	3	2
140	R.H.	95	92	89	87	84	82	79	77	75	73	70	68	66	64	60	54	46	38	31	25	19	14
	EMC	21	19	17	16	15	14	13	12½	12	11½	11	10½	10	9½	9	8	7	6	5	4	3	2½
150	R.H.	95	92	90	87	85	82	80	78	76	74	72	70	68	66	62	57	48	41	34	28	23	18
	EMC	20	18	17	15½	14½	14	13	12½	12	11	11	10½	10	9½	9	8	7	6	5	4	3½	3
160	R.H.	95	93	90	88	86	83	81	79	77	75	73	71	69	67	64	58	50	43	36	31	25	21
	EMC	20	18	16	15	14	13½	13	12	11½	11	10½	10	9½	9½	9	8	7	6	5	4	3½	3
170	R.H.	95	93	91	89	86	84	82	80	78	76	74	72	70	69	65	60	52	45	39	33	28	24
	EMC	19	17½	16	15	14	13	12½	12	11½	11	10½	10	9½	9	8½	8	7	6	5	4½	4	3
180	R.H.	96	94	91	89	87	85	83	81	79	77	75	73	72	70	67	62	54	47	41	35	30	26
	EMC	19	17	15½	14½	13½	13	12	11½	11	10½	10	10	9½	9	8½	8	6½	6	5	4½	4	3

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[1] Relative humidity values on upper lines with heavy type; equilibrium moisture content values on lower lines with light type.

$$\frac{\text{original weight - ovendry weight}}{\text{ovendry weight}} \times 100 \qquad \text{Formula (1)}$$

For example: a section of green walnut weighs 76.0 grams when cut for testing. After ovendrying to constant weight it weighs 40.0 grams. Its moisture content is:

$$\frac{76.0 - 40.0}{40.0} \times 100 = \frac{36.0}{40.0} \times 100 = 0.90 \times 100 = 90 \text{ percent}$$

Electric meter-method. --Electric moisture meters are two general kinds, resistance type (Figure 9) and radio-frequency power-loss type (Figure 10).

Figure 9. --Two sizes of resistance-type moisture meters showing needlepoint electrodes (left) and long, insulated electrodes (right).

Resistance-type meters are usually supplied with short needlepoint electrodes. They may also be obtained with long electrodes that are insulated, except for their tips, with a resin coating. The short electrodes are satisfactory for wood up to 1-1/2 inches thick. When the needles are driven into the wood to a depth equal to one-fifth to one-fourth of its thickness, the resultant meter reading shows the average moisture content of the piece. On material thicker than 1-1/2 inches, the meter reading with short pins would not be reliable unless the wood has a uniform moisture content throughout.

When thick lumber has a drying gradient, the moisture content can be determined by driving two nails, about 1-1/4 inches apart, to a depth of one-fifth the lumber thickness. The needles are held firmly on the nails to get a meter reading. Add a 1 percent correction to the reading to get the average moisture content of the piece.

Figure 10.--A radio-frequency power-loss type of moisture meter.

If the surface of a relatively dry board has become wet from rain, dew, or other moisture, insulated needles are needed for reliable readings with resistance-type meters. Such insulated needles are also long enough to test thick lumber.

The range of operation for accurate readings with the resistance-type meter is from 7 to 25 percent moisture content. The resistance-type meters are generally calibrated at 70°F., so corrections are needed if the wood to be tested is at a different temperature. Corrected values are found from Figure 11.

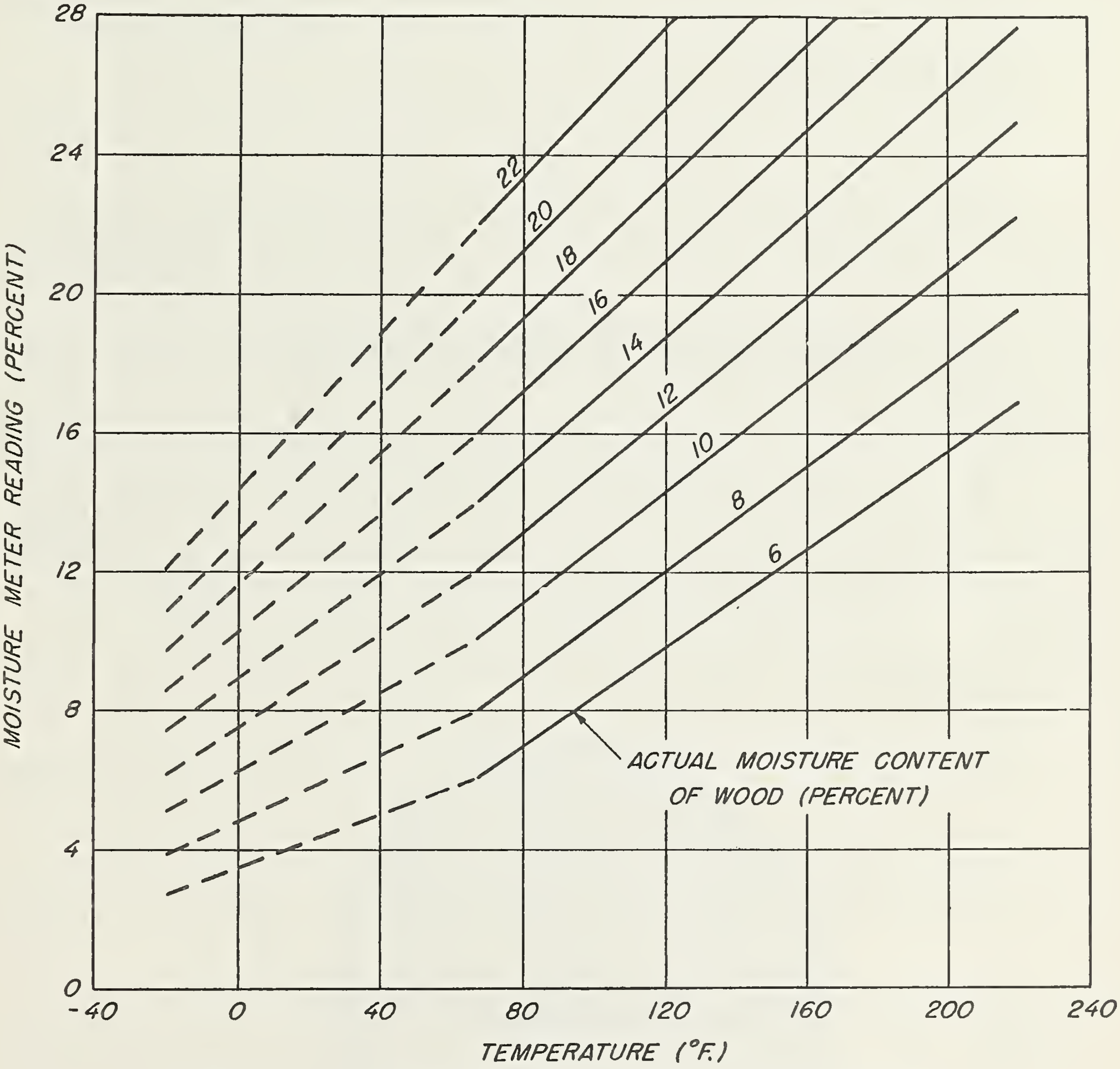

Figure 11. --Temperature correction chart for resistance-type moisture meters.

Power-loss meters have contact electrodes that are applied only to the surface and do not penetrate the wood. Electrodes for lumber consist of a ring of buttons or four separate quadrants of a disk. Electrodes consisting of several concentric rings have been developed for veneer and should not be used on thicker material. Power-loss meters operate from 0 to 25 percent moisture content. No temperature correction values have been stated for them.

Both types of meters require correction factors for different species. The resistance-type meters are accurate to ± 1 percent moisture content; some inaccuracy may be present with the power-loss type of meter when individual boards have specific gravity values considerably different from the average for a species.

SHRINKAGE AND SWELLING

When wood loses moisture below the fiber saturation point, it shrinks. Actually, as a piece of wood dries, it starts to shrink before the average moisture content reaches 30 percent. This is caused by the shrinking of the surface layers, whose moisture content is below 30 percent, and the compression of the wet interior. Theoretically, the shrinkage of wood below the fiber saturation point is directly proportional to the amount of moisture lost. For practical purposes shrinkage can be considered to have a straight-line relationship with the average moisture content. When the moisture content has been reduced to 15 percent, half of the total shrinkage will have occurred.

Total shrinkage, from green to the ovendry condition, varies with species and the three directions of the grain -- tangential, radial, and longitudinal. Tangential shrinkage, which is parallel to the annual growth rings, may be about twice as much as radial shrinkage, which is parallel to the wood rays. When tangential shrinkage is considerably greater than radial shrinkage, serious cupping or distortion of cross section can occur, as shown in Figure 12.

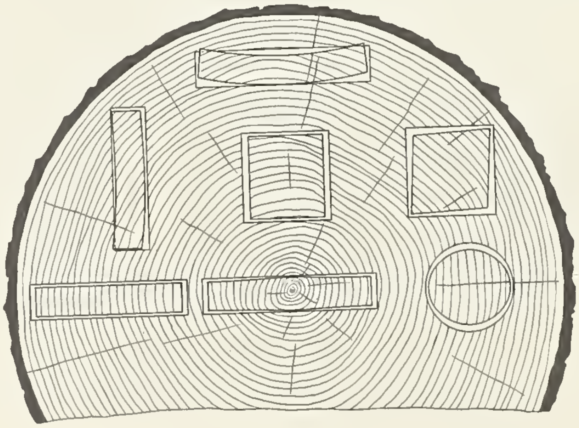

Figure 12. --Distortion resulting from shrinkage in flats, squares, and rounds, as affected by the direction of the growth rings.

Longitudinal shrinkage (along the grain) is generally slight, 0.1 to 0.2 percent. In general, the heavier woods shrink more across the grain (tangential or radial directions) than lighter ones. Abnormal types of wood, such as compression wood, tension wood, and the juvenile wood near the pith, shrink considerably in the longitudinal direction. Table 3 gives radial and tangential shrinkage values for some woods native to the United States. Tables 4 and 5 give approximate radial and tangential shrinkage values for the wood of other species.

Shrinkage Calculations

Dry wood will swell when it soaks up water or absorbs moisture from the air. The percentage of swelling is considered to be equivalent to the percentage of shrinkage for the same moisture change in drying. Approximate changes in dimension with moisture changes can be calculated easily.

The basic method of calculating dimension change is to multiply the dimension of the piece at the start by the appropriate shrinkage value and divide by 100:

$$\frac{\text{shrinkage x original dimension}}{100} = \text{change in dimension}$$

Formula (2)

For example: if flatsawed American beech shrinks 3.7 percent (use tangential value from Table 3 in this case) when drying from green to 20 percent moisture content, how much change in dimension would there be in an 8-inch board?

$$\frac{3.7 \times 8}{100} = \frac{29.6}{100} = 0.296 \text{ or approximately } \frac{3}{10} \text{ inch}$$

The dimension after shrinkage would be 8.00 - 0.30 = 7.70 inch.

If the lumber were dried to 20 percent moisture content in the rough form and then sawed to an 8-inch width, what would its dimension be if it were dried further to 12 percent moisture content?

In this case, the percentage shrinkage value would be the difference between the 12 percent value (Table 3) and the 20 percent value: 6.6 - 3.7 = 2.9 percent. The change is $\frac{2.9 \times 8}{100} = \frac{23.2}{100} = 0.232$ inch. The new dimension is 8 - 0.23 = 7.77 inch.

The formula may be used approximately for change in dimension between any moisture content values by bringing in the fiber saturation point value of 30. For example, how much will a board that is 8 inches wide at 10 percent moisture content swell in going to 19 percent moisture content?

In this case the percentage shrinkage value of 11.0 is divided by 30 to get 0.367 percent shrinkage or swelling per 1 percent change in moisture

Table 3.--Shrinkage values of some North American and imported woods based on dimensions of the wood when green[1]

Species		Shrinkage					
Botanical name	Common name[2]	Dried to 20 percent moisture content[3]		Dried to 12 percent moisture content[4]		Dried to 0 percent moisture content	
		Radial	Tangential	Radial	Tangential	Radial	Tangential
		Percent	Percent	Percent	Percent	Percent	Percent
		HARDWOODS					
Acer saccharinum	Maple, silver	1.0	2.4	1.8	4.3	3.0	7.2
Acer saccharum	Maple, sugar	1.6	3.2	2.9	5.7	4.9	9.5
Aesculus octandra	Buckeye, yellow	1.2	2.7	2.2	4.9	3.6	8.1
Alnus rubra	Alder, red	1.5	2.4	2.6	4.4	4.4	7.3
Betula alleghaniensis	Birch, yellow	2.4	3.1	4.3	5.5	7.2	9.2
Betula papyrifera	Birch, paper	2.1	2.9	3.8	5.2	6.3	8.6
Carya aquatica	Hickory, water	1.6	3.0	2.9	5.3	4.9	8.9
Carya glabra	Hickory, pignut	2.4	3.8	4.3	6.9	7.2	11.5
Castanea dentata	Chestnut	1.1	2.2	2.0	4.0	3.4	6.7
Celtis occidentalis	Hackberry	1.6	3.0	2.9	5.3	4.8	8.9
Cornus florida	Dogwood, flowering	2.5	3.9	4.4	7.1	7.4	11.8
Diospyros virginiana	Persimmon	2.6	3.7	4.7	6.7	7.9	11.2
Fagus grandifolia	Beech	1.7	3.7	3.1	6.6	5.1	11.0
Fraxinus americana	Ash, white	1.6	2.6	2.9	4.7	4.8	7.8
Gleditsia triacanthos	Honeylocust	1.4	2.2	2.5	4.0	4.2	6.6
Ilex opaca	Holly, American	1.6	3.3	2.9	5.9	4.8	9.9
Juglans nigra	Walnut, black	1.8	2.6	3.3	4.7	5.5	7.8
Liquidambar styraciflua	Sweetgum	1.7	3.3	3.1	5.9	5.2	9.9
Liriodendron tulipifera	Yellow-poplar	1.3	2.4	2.4	4.3	4.0	7.1
Magnolia grandiflora	Magnolia, southern	1.8	2.2	3.2	4.0	5.4	6.6
Nyssa aquatica	Tupelo, water	1.4	2.5	2.5	4.6	4.2	7.6
Nyssa sylvatica	Tupelo, black	1.5	2.6	2.6	4.6	4.4	7.7
Ostrya virginiana	Hophornbeam, eastern	2.8	3.3	5.1	6.0	8.5	10.0
Platanus occidentalis	Sycamore, American	1.7	2.5	3.1	4.6	5.1	7.6

See footnotes at end of table.

Table 3.--Shrinkage values of some North American and imported woods based on dimensions of the wood when green[1]--Continued

Species		Shrinkage					
Botanical name	Common name[2]	Dried to 20 percent moisture content[3]		Dried to 12 percent moisture content[4]		Dried to 0 percent moisture content	
		Radial	Tangential	Radial	Tangential	Radial	Tangential
		Percent	Percent	Percent	Percent	Percent	Percent
		HARDWOODS--Continued					
Populus deltoides	Cottonwood, eastern	1.3	3.1	2.3	5.5	3.9	9.2
Populus tremuloides	Aspen, quaking	1.2	2.2	2.1	4.0	3.5	6.7
Prunus serotina	Cherry, black	1.2	2.4	2.2	4.3	3.7	7.1
Quercus alba	Oak, white	1.8	3.0	3.2	5.4	5.3	9.0
Quercus falcata	Oak, southern red	1.5	2.9	2.7	5.2	4.5	8.7
Quercus rubra	Oak, northern red	1.3	2.7	2.4	4.9	4.0	8.2
Robinia pseudoacacia	Locust, black	1.5	2.4	2.8	4.3	4.6	7.2
Salix nigra	Willow, black	.9	2.7	1.6	4.9	2.6	8.1
Tilia americana	Basswood, American	2.2	3.1	4.0	5.6	6.6	9.3
Ulmus americana	Elm, American	1.4	3.2	2.5	5.7	4.2	9.5
Ulmus thomasii	Elm, rock	1.6	2.7	2.9	4.9	4.8	8.1
		SOFTWOODS					
Abies amabilis	Fir, Pacific silver	1.5	3.3	2.8	5.9	4.6	9.8
Abies concolor	Fir, white	1.1	2.4	1.9	4.3	3.2	7.1
Abies grandis	Fir, grand	1.1	2.5	2.0	4.5	3.4	7.5
Abies procera	Fir, noble	1.5	2.7	2.7	4.9	4.5	8.2
Chamaecyparis lawsoniana	Port-Orford-cedar	1.5	2.3	2.8	4.1	4.6	6.9
Chamaecyparis nootkatensis	Alaska-cedar	.9	2.0	1.7	3.6	2.8	6.0
Juniperus virginiana	Eastern redcedar	1.0	1.6	1.9	2.8	3.1	4.7
Larix occidentalis	Larch, western	1.4	2.7	2.5	4.9	4.2	8.1
Libocedrus decurrens	Incense-cedar	1.1	1.7	2.0	3.1	3.3	5.2

See footnotes at end of table.

Table 3.--Shrinkage values of some North American and imported woods based on dimensions of the wood when green[1]--Continued

Species		Shrinkage					
Botanical name	Common name[2]	Dried to 20 percent moisture content[3]		Dried to 12 percent moisture content[4]		Dried to 0 percent moisture content	
		Radial	Tangential	Radial	Tangential	Radial	Tangential
		Percent	Percent	Percent	Percent	Percent	Percent
		SOFTWOODS--Continued					
Picea rubens	Spruce, red	1.3	2.6	2.3	4.7	3.8	7.8
Picea sitchensis	Spruce, Sitka	1.4	2.5	2.6	4.5	4.3	7.5
Pinus contorta	Pine, lodgepole	1.5	2.2	2.7	4.0	4.5	6.7
Pinus echinata	Pine, shortleaf	1.5	2.6	2.6	4.6	4.4	7.7
Pinus lambertiana	Pine, sugar	1.0	1.9	1.7	3.4	2.9	5.6
Pinus monticola	Pine, western white	1.4	2.5	2.5	4.4	4.1	7.4
Pinus palustris	Pine, longleaf	1.7	2.5	3.1	4.5	5.1	7.5
Pinus ponderosa	Pine, ponderosa	1.3	2.1	2.3	3.8	3.9	6.3
Pinus strobus	Pine, eastern white	.8	2.0	1.4	3.6	2.3	6.0
Pinus taeda	Pine, loblolly	1.6	2.5	2.9	4.4	4.8	7.4
Pseudotsuga menziesii	Douglas-fir, Coast	1.7	2.6	3.0	4.7	5.0	7.8
	Douglas-fir, Rocky Mountain	1.2	2.1	2.2	3.7	3.6	6.2
Sequoia sempervirens	Redwood	.9	1.5	1.6	2.6	2.6	4.4
Taxodium distichum	Baldcypress	1.3	2.1	2.3	3.7	3.8	6.2
Thuja plicata	Redcedar, western	.8	1.7	1.4	3.0	2.4	5.0
Tsuga canadensis	Hemlock, eastern	1.0	2.3	1.8	4.1	3.0	6.8
Tsuga heterophylla	Hemlock, western	1.4	2.6	2.6	4.7	4.3	7.9
		SOME HARDWOODS IMPORTED INTO THE UNITED STATES					
Chlorophora excelsa	Iroko	1.1	1.6	2.0	2.9	3.4	4.8
Eucalyptus crebra	Ironbark, gray	1.9	2.8	3.4	5.0	5.6	8.4

See footnotes at end of table.

Table 3.--Shrinkage values of some North American and imported woods based on dimensions of the wood when green[1]--Continued

Species		Shrinkage					
Botanical name	Common name[2]	Dried to 20 percent moisture content[3]		Dried to 12 percent moisture content[4]		Dried to 0 percent moisture content	
		Radial	Tangential	Radial	Tangential	Radial	Tangential
		Percent	Percent	Percent	Percent	Percent	Percent
SOME HARDWOODS IMPORTED INTO THE UNITED STATES--Continued							
Khaya sp.	Khaya	1.4	1.9	2.5	3.5	4.1	5.8
Ocotea rodiaei	Greenheart	1.1	1.4	2.0	2.5	3.4	4.2
Shorea negrosensis	Lauan, red	1.1	2.7	2.0	4.8	3.3	8.0
Shorea polysperma	Tangile	1.4	3.0	2.6	5.5	4.3	9.1
Swietenia macrophylla	Mahogany	1.2	1.7	2.2	3.0	3.6	5.0
Tectona grandis	Teak	.8	1.4	1.4	2.5	2.3	4.2

[1] Data from "Wood Handbook" (Appendix A).

[2] From "Check List of Native and Naturalized Trees of the United States" (Appendix A).

[3] These shrinkage values have been taken as 1/3 of the shrinkage to the ovendry condition as given in the last 2 columns of this table.

[4] These shrinkage values have been taken as 3/5 of the shrinkage to the ovendry condition as given in the last 2 columns of this table.

Table 4.--Shrinkage values of tropical species based on green dimensions[1]

Species		Shrinkage to 0 percent moisture content[3]	
Botanical name	Common name[2]	Radial	Tangential
		Percent	Percent
Agathis lanceolata	Kaori rouge (Kauri)	5.2	7.2
Albizzia ferruginea	Yatandza	3.4	4.9
Albizzia granulosa	Acacia noir	6.5	9.9
Albizzia lebbeck	Bois noir	3.0	5.4
Aleurites moluccana	Bancoulier	3.7	7.0
Alphitonia neocaledonica	Pomaderris	5.5	7.6
Alstonia congensis	Ekouk	3.8	5.2
	Emien (Glistonia, mujua)	3.4	5.1
Antiaris africana	Ako (Antiaris)	4.4	7.2
Antracaryon klaineanum	Onzabilli	5.3	7.9
Antracaryon micraster	Onzabilli	4.8	7.4
Araucaria cookii	Pin colonnaire	2.5	3.7
Baillonella toxisperma	Moabi	6.0	7.7
Beauprea spathulaefolia	Hêtre rouge	2.3	10.2
Beilschmiedia nitida	Todo	3.8	4.8
Blighia welwitschii	Kaka	6.5	10.3
Brachystegia zenkeri	Yegna	2.9	4.8
Brevica sericea	Apobeaou	6.1	8.3
Bridelia aubrevillei	Tchikuebi	3.1	7.6
Bridelia micrantha	Tchikué	3.8	6.1
Canarium sp.	Ramy blanc	5.2	7.1
Carissa sp.	Hazondronono	5.0	8.4
Casuarina cunninghamiana	Bois de fer de rivière	5.2	11.5
Ceiba pentandra	Fromager (Ceiba)	2.9	4.3
Celtis soyauxii	Ba (Celtis, African)	5.2	7.8
Cerberiopsis candelabra	Candĕlabre	6.5	14.5
Chrysophyllum amieuanum	Feuilles rousses	5.5	9.5
Combretodendron africanum	Abalé (Essia)	5.5	9.4
Copaifera mildbraedii	N'Kara	5.7	7.8
Copaifera religiosa	Anzém	3.7	4.3
Copaifera salikounda	Etimoé	5.1	8.4
Cordia platythyrasa	Ebé	3.5	4.6
Coula edulis	Coula	4.8	9.1
Craspidospermum verticillatum	Vandrika	5.1	9.3
Crossostylis multiflora	Hêtre	3.2	9.0

See footnotes at end of table.

Table 4.--Shrinkage values of tropical species based on green dimensions[1]--Continued

Species		Shrinkage to 0 percent moisture content[3]	
Botanical name	Common name[2]	Radial	Tangential
		Percent	Percent
Cryptocarya sp.	Citronelle	5.8	8.1
Cryptocarya elliptica	Faux santal	6.1	9.2
Cryptocarya louvelii	Longotra rouge	3.5	6.4
Cryptosepalum staudtii	Tani	5.2	10.3
Cunonia austrocaledonica	Chêne	5.7	8.9
Cylicodiscus gabunensis	Bouémon	3.8	8.3
Dacryodes sp.	Mouguengueri	5.2	8.2
Dacryodes sp.	Ozigo	5.3	7.2
Dacryodes sp.	Safoukala	4.4	5.8
Dacryodes buttneri	Ozigo	7.4	9.4
Dacryodes klaineana	Adjouaba	7.4	8.3
Dacryodes le testui	Ozigo	5.0	8.5
Daniellia oliveri	Sandan	3.3	6.0
Daniellia soyauxii	Singa N'Dola	3.9	8.8
Dialium cochinchinese	Xoay	5.2	9.1
Dipterocarpus obtusifolius	Dau	5.3	9.4
Discoglypremna caloneura	Akoret	3.8	7.0
Drypetis gossweileri	Tchissakata	4.5	10.2
Dyxoxylum macranthum	Bois d'ail	6.5	9.9
Elaeocarpus speciosus	Azou graines bleues	4.2	8.3
Entandrophragma angolense	Tiama (Gedu; nohor, mukusa)	4.8	6.5
Erythrophleum micranthum	Tali (Missanda; tali)	4.6	7.3
Erythrophleum perpulchrum	Longui	5.9	9.7
Euroschinus vieillardii	Térébenthine	2.9	6.5
Fagraea schlechteri	Bois tabou	2.6	5.2
Fauchera sp.	Nato	4.9	7.8
Flindersia fournieri	Chêne blanc	7.8	10.7
Geissais racemosa	Faux Tamanou	5.0	7.8
Gilbertiodendron sp.	Ekobem	3.1	6.9
Gilbertiodendron dewevrei	Molapa	5.4	9.7
Gilbertiodendron splendidum	Médjilagba	4.2	8.4
Guibourtia tessmannii	Bubinga	4.9	5.9

See footnotes at end of table.

Table 4.--Shrinkage values of tropical species based on green dimensions[1]--Continued

Species		Shrinkage to 0 percent moisture content[3]	
Botanical name	Common name[2]	Radial	Tangential
		Percent	Percent
Hernandia cordigera	Bois bleu	3.8	7.0
Homalium dolichophyllum	Méléfoufou	7.0	9.5
Ilex serbertii	Collier blanc	5.7	11.2
Intsia bijuga	Kohu	1.8	4.0
Irvingia gabonensis	Boborou	6.5	10.2
Irvingia grandifolia	Oléne	8.1	9.1
Kermadecia leptophylla	Hêtre blanc	2.7	8.7
Keteleeria davidiana	Ngo tung	2.4	5.5
Khaya senegalensis	Cail cedrát	5.3	5.9
Klainedoxa gabonensis	Oban ngon	8.3	9.9
Lophira alata	Azobé	6.5	10.7
	Bongossi	6.1	9.6
Mammea africana	Oboto	6.5	8.3
	Oboto du djimbo	5.7	9.1
Melaleuca leucadendron	Niaouli	5.4	10.1
Microberlinia bisulcata	Zingana	4.5	8.7
Microberlinia brazzavillensis	Zingana (Zebrano)	4.8	9.1
Mitragyna ciliata	Bahia (abura)	4.2	8.8
Mitragyna stipulosa	Bahia	4.8	9.5
Neoguillauminia cleopatra	Euphorbe	3.7	7.3
Nesogordonia papaverifera	Kotibé	4.8	4.8
	Kotibé ou ovoé	5.8	8.3
Ongokea gore	Angueuk	4.7	----
	Kouero	4.3	10.7
Pancheria brunhesii	Chene rouge	6.4	8.3
Parinari robusta	Koaramon	8.3	10.7
Pentadesma butyracea	Kandika	4.5	8.0
Phyllarthron madagascariense	Zahana	5.3	8.7
Piliocalyx laurifolius	Goya	3.7	7.2
Pinus khasya	Pin	6.5	7.4
Piptadeniastrum africanum	Dabema (Dahoma, ekhimi)	2.5	8.0

See footnotes at end of table.

Table 4.--Shrinkage values of tropical species based on green dimensions[1]-- Continued

Species		Shrinkage to 0 percent moisture content[3]	
Botanical name	Common name[2]	Radial	Tangential
		Percent	Percent
Pithecellobium altissimum	Gongoi	4.4	6.9
Pithecellobium dinklagei	Gongoi	5.7	7.8
Polyscias ornifolia	Vohantsilana	4.9	7.8
Pycnanthus angolensis	Ilomba (Ilomba; akomu)	3.9	7.8
Sarcocephalus diderrichii	Badi	4.8	7.4
Scottellia chevalieri	Akossika á grandes feuilles	3.8	7.8
Scottellia kamerunensis	Akossika á petites feuilles	----	7.8
Scorodophloeus zenkeri	Divida	5.7	10.0
Shorea vulgaris	Chaï	3.8	7.0
Spermolepis gummerifera	Chêne gomme	7.0	10.6
Stemonocoleus micranthus	Kivala	3.4	4.9
Strephonema pseudocola	Potopoto	5.7	11.1
Strombosia glaucensens var. lucida	Poé	7.6	7.9
Swartzia fistuloides	Kiela-Kussu	4.1	5.7
Syzygium sp.	Kivala	5.4	8.8
Tarrietia utilis	Niangon	2.9	5.9
Terminalia catappa	Amandier	5.7	11.1
Terminalia celerica	Chieu-lieu	4.8	7.0
Terminalia ivorensis	Framiré (Afara, black; idigbo)	3.1	4.9
Terminalia superba	Fraké	4.1	5.7
	Limbo (Limba; limbo)	4.5	5.2
Tetraberlinia bifoliolata	Andoung	4.2	6.4
Tieghemopanax microcarpus	Bois carotte	9.3	11.5
Triplaris surinamensis	Bois fourmi	2.6	5.8
Triplochiton scleroxylon	Ayous	3.6	5.9
Triplochiton scleroxylon	Samba (Obeche; wawa)	3.3	5.4
Turraeanthus africana	Avodiré (Avodiré)	3.4	5.9
Uapaca paludosa	Rikio á grandes feuilles	5.9	11.3
Uapaca thouarsii	Voapaka	5.8	10.8
Vitex micrantha	Andofiti	2.7	5.8

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[1] Data from "Propriétés Physiques et Mécaniques des Bois Tropicaux de L'Union Francáise," (Appendix A).

[2] English common names are given in parentheses.

[3] Volumetric shrinkage data are given in the original reference.

Table 5. --Shrinkage of species imported into Great Britain

Species		Shrinkage to 0 percent moisture content[1]	
Botanical name	Common name	Radial	Tangential
		Percent	Percent
Afrormosia elata	Kokrodua	2.5	4.1
Afzelia bipindensis	Afzelia	1.4	2.6
Berlinia sp.	Berlinia	4.9	8.2
Brachystegia boehmii	Mjombo	5.6	8.2
Brachystegia spiciformis	Mtondo	4.9	6.8
Catostemma commune	Baromalli	7.4	13.3
Cedrela fissilis	Cedar, South American	5.2	6.6
Cynometra alexandri	Muhimbi	4.3	8.2
Daniellia ogea	Ogea	2.5	7.0
Dumoria heckelii	Makoré	4.7	7.0
Gonystylus bancanus	Ramin	4.3	8.7
Gossweilerodendron balsamiferum	Agba	2.8	5.2
Isoberlinia globiflora	Mchenga	5.2	7.8
Lophira alata	Ekki	8.3	9.6
Mora gonggrijpii	Morabukea	6.9	12.2
Nesogordonia papaverifera	Danta	3.2	8.7
Octomeles sumatrana	Binuang	5.2	12.0
Parinari excelsa	Mubura	5.5	8.5
Pterygota kamerunensis	Pterygota	3.3	8.2
Sterculia oblonga	Sterculia, yellow	6.1	11.3
Sterculia pruriens	Maho	4.8	11.9
Tabebuia sp.	Lapacho	2.9	4.5

[1] These are approximate values calculated from data contained in "A Handbook of Hardwoods," (Appendix A).

content. The moisture content difference is 19 - 10 or 9 percent. Then the appropriate swelling value for the example is 9 x 0.367 or 3.3 percent.

$$\frac{3.3 \times 8}{100} = \frac{26.4}{100} = 0.264 \text{ inch}$$

The dimension of the board after swelling would be 8 + 0.26 = 8.26 inches.

A formula for more exact computation of shrinkage or swelling between any two moisture content values is given in Appendix G. In using such formulas, the moisture content value used for green wood is 30 percent, the point where shrinkage starts. When quartersawed boards are used, the radial shrinkage values from the Table are used.

Calculated shrinkage and swelling will seldom be exactly correct for an individual board because individual boards vary in tendency to shrink, while the values shown in Table 3 are the averages for many boards. Also, shrinkage is not exactly a straight-line relationship between 30 and 0 percent moisture content.

HOW WOOD DRIES

A board or other piece of wood dries by evaporation of moisture from the surfaces. In a board, for example, most of the moisture is evaporated from the broad faces. Evaporation takes place when the moisture content of the surfaces is above the EMC corresponding to the relative humidity and temperature of the surrounding air. Green wood will dry at any relative humidity below 100 percent. Evaporation from the surfaces soon causes them to reach a moisture content in balance with the relative humidity and temperature of the air. The moisture in the surface layers, however, is continually replenished by moisture moving outward from the wetter interior parts of the piece of wood. A moisture gradient is set up with a gradual change from the low surface moisture content to the high moisture content at midthickness. If the relative humidity and temperature of the air in contact with the piece of wood remain constant, drying will continue until the whole piece of wood approaches the equilibrium moisture content value. Prolonging the drying time indefinitely will not result in further drying.

The method and rate of movement of moisture in wood are important in wood drying. Moisture moves in the three directions of the grain: Longitudinally, radially, and tangentially. Movement is most rapid in the longitudinal direction and slowest in the tangential direction. The water may move as a liquid, as a vapor, or as both. Liquid movement takes place as a result of capillary action of the free water or diffusion of the bound water in the cell walls. The movement of vapor is by diffusion. When wood is at a temperature below 32°F. most of the water is frozen and movement is slow.

Water moves through the cell cavities, through the perforations in the bordered pit membranes, and through the cell walls. Water moves more rapidly in wood of low specific gravity than in wood of high specific gravity. It generally moves more rapidly in sapwood than it does in heartwood of the same species. This difference probably stems from the fact that the openings in the wood structure of heartwood are partially plugged by extractives. Moisture, both as liquid and as vapor, moves more rapidly at high than at low temperatures. Moisture moves from zones of high moisture content to zones of low moisture content, in response to the potential created by the difference in moisture content or the steepness of the moisture gradient. Low relative humidity also stimulates diffusion by lowering the surface moisture content. Moisture vapor diffuses in response to differences in vapor pressure.

Because wood dries by evaporation of moisture from the surfaces and by movement of moisture from the interior to the surfaces, the surfaces are usually at a lower moisture content than the interior zones. This scheme is interrupted temporarily when lumber that is air drying is exposed to a period of damp weather after a period of dry weather. In this temporary situation, the zone just beneath the surface will be at a lower moisture content than the surface. This also holds true in kiln drying when the lumber is given an equalizing or conditioning treatment near the end of the kiln-drying process.

In summary, high temperatures and low relative humidity stimulate moisture movement and speed up drying. These conditions, however, can not be overused or end, surface, and honeycomb checking, collapse, excessive shrinkage, and warping may result. Therefore, careful air drying procedures and appropriate kiln schedules are necessary to control these factors during drying.

MOISTURE CONTENT OF WOOD FOR DIFFERENT USES

Any piece of wood will give off or take on moisture from the air until the amount of moisture in the wood is in balance with that in the air. If wood could be kept in constant conditions, it would finally come to equilibrium values like those shown in Table 2. Wood in service, however, is exposed to daily and seasonal changes in temperature and relative humidity. Thus wood is usually undergoing changes in moisture content. These changes are gradual and are slowed down by surface finishes. The practical object of any complete seasoning process is to dry the wood to a moisture content in equilibrium with the average air conditions it will be exposed to in service.

For exterior use everywhere and interior use in areas where no major interior heating is used the year around, the moisture content of wood roughly parallels outdoor relative humidity. Interior moisture values are usually slightly lower than corresponding exterior values.

As an example of the wide variations that may occur, Figure 13 shows interior woodwork moisture content in July throughout the United States. Table 6 gives outdoor moisture content values in several United States cities for each month of the year. These values are averages for all the various woods native to the United States. In temperate climates most woods differ little from these values. Tropical woods may be somewhat different.

Table 6.--Equilibrium moisture content of wood, exposed to outdoor atmosphere, in the United States

Location	January	February	March	April	May	June	July	August	September	October	November	December
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Portland, Maine	17	15-1/2	16	15	15	13-1/2	14	15-1/2	17	15-1/2	16-1/2	15
Wilmington, Del.	15	12	13-1/2	12-1/2	13-1/2	12-1/2	12-1/2	13	14-1/2	14	14-1/2	13-1/2
Charleston, S. C.	15	15	13	13-1/2	14	15-1/2	16	17	17	16	15-1/2	16
Key West, Fla.	14-1/2	14-1/2	14-1/2	13	13-1/2	14	14	13	14-1/2	16-1/2	16	15
Cleveland, Ohio	17	15	15	13-1/2	13	12	11-1/2	12-1/2	12	10	13-1/2	15
Charleston, W. Va.	14-1/2	12	12	12	12-1/2	14	14	14	12-1/2	11-1/2	12	13-1/2
Nashville, Tenn.	15-1/2	14	13	12	12-1/2	11-1/2	12	12	12	11-1/2	12	15
Mobile, Ala.	16	16	14-1/2	13-1/2	15	14	15-1/2	16-1/2	14-1/2	12	13	15
Milwaukee, Wis.	16	14-1/2	15	12-1/2	13	13-1/2	13	14	13	12	13	16
Des Moines, Iowa	17	16	15	12-1/2	13	13-1/2	13-1/2	13-1/2	11-1/2	10	12-1/2	16-1/2
Wichita, Kans.	13-1/2	12-1/2	13	12	12	10	11	10-1/2	8-1/2	8-1/2	12	15-1/2
Galveston, Tex.	18	18	18	16	17	15-1/2	15-1/2	15-1/2	15-1/2	14	16-1/2	16
Huron, S. Dak.	17	18	16	12-1/2	12	13	12	12	10	10	13-1/2	17-1/2
Casper, Wyo.	11	12-1/2	11-1/2	10-1/2	11	8-1/2	8-1/2	8	7	8	11	13
Denver, Colo.	8-1/2	8-1/2	9-1/2	10-1/2	10	7-1/2	8	9	7	7	10	10-1/2
Tucson, Ariz.	9	7	8	7	5-1/2	4-1/2	8	8	5	5	7-1/2	8
Seattle, Wash.	21	19	17	15	14	15-1/2	13-1/2	14-1/2	14-1/2	17	19	19
Portland, Oreg.	19-1/2	17	14-1/2	13	14	14-1/2	12	13-1/2	13	16	18-1/2	20
San Francisco, Calif.	18-1/2	15	14-1/2	16	14-1/2	15-1/2	16	16-1/2	15-1/2	16	16	16-1/2
Honolulu, Hawaii	14	13-1/2	13	12-1/2	12	12	12-1/2	12-1/2	12	13	13	13-1/2

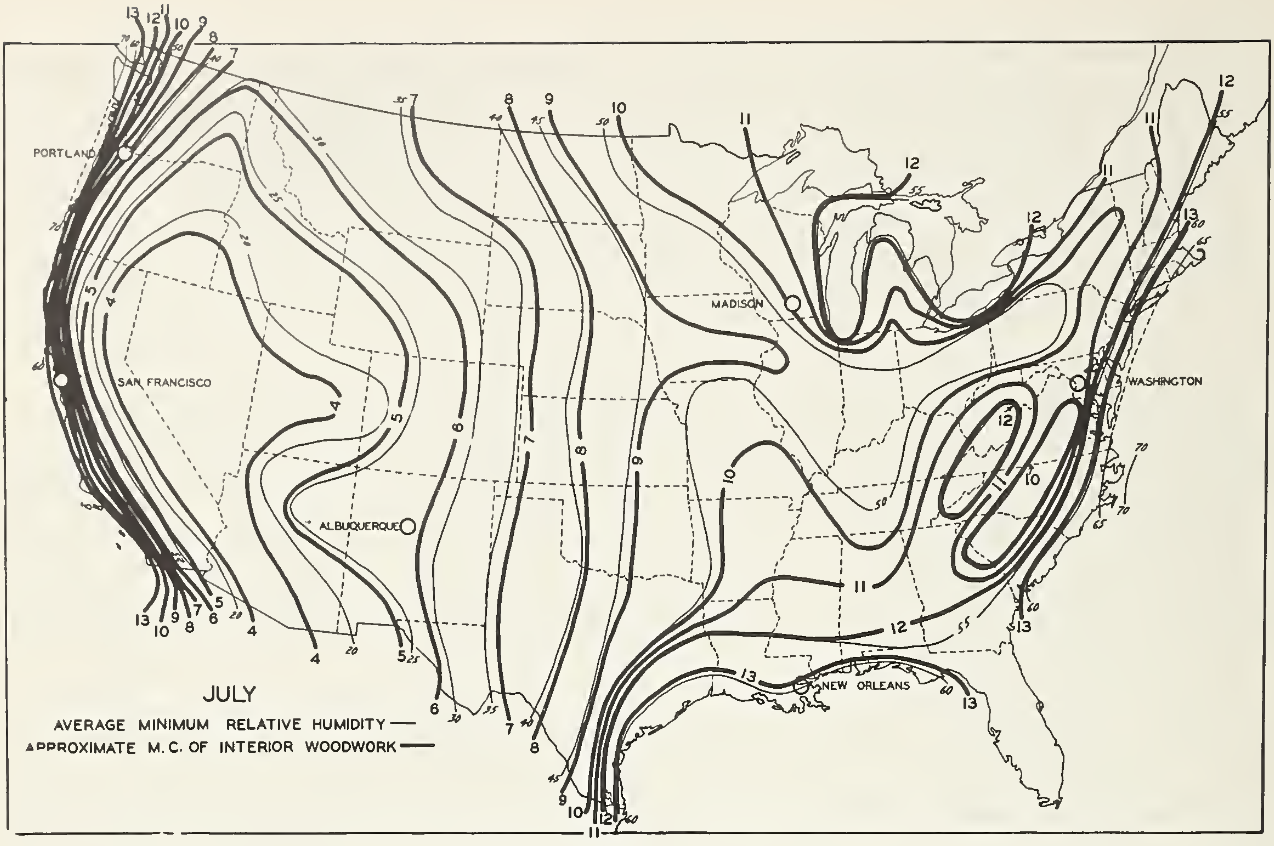


Figure 13.--Moisture content of interior woodwork and average minimum outdoor relative humidity in the United States during July.

When wood is to be used in a building equipped with a central heating plant, the moisture content to which it should be dried is the average of the highest moisture content and the lowest moisture content it will have during the year. When winter air, which is low in absolute humidity, is heated in a building to about 70°F., the relative humidity and the equilibrium moisture content both go down. The lower the outdoor temperature and the higher the degree of artificial heating the lower will be the equilibrium moisture content.

As a result of summer EMC values and low winter EMC values in heated living rooms and offices, the average moisture content value for furniture in the northern United States is about 8 percent. In England, the average is about 11 percent, and in the continental Europe it is about 10 percent. In England the furniture in bedrooms, where less heating is used, comes to about 13-1/2 percent average moisture content.

SPECIFIC GRAVITY AND WEIGHT OF WOOD

All wood cell wall substance, regardless of the species from which it comes, has a specific gravity of about 1.46. The differences between species in weight of dry wood arise from the cellular structure of the wood and the relative amounts of cell walls and cell cavities. The moisture that is in wood adds to its weight. Most species of wood, even when green, float in water. Table 7 gives the weights of wood of typical North American species under different conditions of moisture content.

COLOR OF WOOD

The color of wood ranges from almost pure white to black. The sapwood of American holly is almost pure white in color, while the heartwood of ebony is dead black. The sapwood of most species is light colored and can perhaps be described as yellowish white. The heartwood of most species is distinctly darker than the sapwood, and there is great variation between species. The colors are generally a combination of yellow, brown, and red. Sometimes a greenish or purplish tint is present. When wood is exposed to air and light, the color becomes duller and darker. Wood exposed in air-drying yards also becomes discolored through airborne dust or soot. The surface discoloration caused by exposure to air and sunshine or dirt does not penetrate very far into the wood, except into surface checks, and is removed in planing.

Table 7.--Average weight of some North American woods under different conditions of moisture content, with adjustment factors for moisture content changes [1]

Botanical name	Common name [2]	Weight per cubic foot			Weight per 1,000 board feet (15 percent moisture content)	
		Based on weight and volume at a moisture content of 15 percent	Based on weight and volume at a moisture content of 8 percent	Factors [3] for adjusting value for each 1 percent change in moisture content	Actual [4] board feet	Dressed (1 by 8 dressed to 25/32 by 7-1/2)
		Pounds	Pounds		Pounds	Pounds
		HARDWOODS				
Acer saccharinum	Maple, silver	33.9	32.8	0.154	2,820	2,070
Acer saccharum	Maple, sugar	44.5	43.4	.154	3,710	2,720
Aesculus octandra	Buckeye, yellow	25.5	24.8	.104	2,120	1,550
Alnus rubra	Alder, red	28.8	28.0	.112	2,400	1,760
Betula alleghaniensis	Birch, yellow	43.4	42.4	.142	3,620	2,650
Betula papyrifera	Birch, paper	38.9	38.2	.095	3,240	2,370
Carya aquatica	Hickory, water	44.6	42.3	.329	3,720	2,720
Carya glabra	Hickory, pignut	53.4	52.6	.120	4,450	3,260
Castanea dentata	Chestnut, American	30.5	29.5	.145	2,540	1,860
Celtis occidentalis	Hackberry	37.4	36.2	.175	3,120	2,290
Cornus florida	Dogwood, flowering	51.5	50.7	.120	4,290	3,140
Diospyros virginiana	Persimmon, common	50.8	49.7	.158	4,230	3,100
Fagus grandifolia	Beech, American	44.3	43.2	.162	3,690	2,700
Fraxinus americana	Ash, white	42.7	41.5	.175	3,560	2,610
Ilex opaca	Holly, American	39.8	38.9	.133	3,320	2,430
Juglans nigra	Walnut, black	38.6	37.0	.233	3,220	2,360
Liquidambar styraciflua	Sweetgum	36.4	35.5	.133	3,030	2,220
Liriodendron tulipifera	Yellow-poplar	30.3	29.2	.150	2,520	1,850
Magnolia grandiflora	Magnolia, southern	35.5	34.4	.162	2,960	2,170
Nyssa aquatica	Tupelo, water	35.1	34.0	.162	2,920	2,140
Nyssa sylvatica	Tupelo, black	36.4	35.5	.129	3,030	2,220

See footnotes at end of table.

Table 7.--Average weight of some North American woods under different conditions of moisture content, with adjustment factors for moisture content changes[1]--Continued

Botanical name	Common name[2]	Weight per cubic foot			Weight per 1,000 board feet (15 percent moisture content)	
		Based on weight and volume at a moisture content of 15 percent	Based on weight and volume at a moisture content of 8 percent	Factors[3] for adjusting value for each 1 percent change in moisture content	Actual[4] board feet	Dressed (1 by 8 dressed to 25/32 by 7-1/2)
		Pounds	Pounds		Pounds	Pounds
		HARDWOODS--Continued				
Ostrya virginiana	Hophornbeam, eastern	50.0	48.8	0.167	4,170	3,050
Platanus occidentalis	Sycamore, American	35.7	34.7	.137	2,970	2,180
Populus deltoides	Cottonwood, eastern	28.9	28.0	.125	2,410	1,770
Populus tremuloides	Aspen, quaking	27.0	26.1	.129	2,250	1,650
Prunus serotina	Cherry, black	36.1	34.8	.183	3,010	2,200
Quercus alba	Oak, white	46.8	45.6	.167	3,900	2,860
Quercus falcata	Oak, southern red	41.1	42.5	.187	3,650	2,670
Quercus rubra	Oak, northern red	43.8	40.1	.142	3,420	2,500
Robinia pseudoacacia	Locust, black	49.0	46.7	.324	4,080	2,990
Salix nigra	Willow, black	27.6	26.9	.104	2,300	1,680
Tilia americana	Basswood, American	26.0	25.5	.075	2,170	1,590
Ulmus americana	Elm, American	36.3	35.5	.117	3,020	2,210
Ulmus thomasii	Elm, rock	44.2	42.7	.208	3,680	2,700
		SOFTWOODS				
Abies amabilis	Fir, Pacific silver	28.1	27.3	0.117	2,340	1,710
Abies concolor	Fir, white	26.7	25.8	.129	2,220	1,630
Abies grandis	Fir, grand	28.3	27.3	.145	2,360	1,730
Abies procera	Fir, noble	27.1	26.2	.129	2,260	1,660

See footnotes at end of table.

Table 7.--Average weight of some North American woods under different conditions of moisture content, with adjustment factors for moisture content changes[1]--Continued

Botanical name	Common name[2]	Weight per cubic foot			Weight per 1,000 board feet (15 percent moisture content)	
		Based on weight and volume at a moisture content of 15 percent	Based on weight and volume at a moisture content of 8 percent	Factors[3] for adjusting value for each 1 percent change in moisture content	Actual[4] board feet	Dressed (1 by 8 dressed to 25/32 by 7-1/2)
		Pounds	Pounds		Pounds	Pounds
		SOFTWOODS--Continued				
Chamaecyparis lawsoniana	Port-Orford-cedar	30.1	28.9	0.175	2,510	1,840
Chamaecyparis nootkatensis	Alaska-cedar	31.6	30.4	.170	2,630	1,930
Juniperus virginiana	Redcedar, eastern	33.5	32.2	.187	2,790	2,040
Larix occidentalis	Larch, western	39.4	38.2	.170	3,280	2,400
Libocedrus decurrens	Incense-cedar	25.5	24.2	.183	2,120	1,550
Picea glauca	Spruce, white	29.4	28.7	.104	2,450	1,790
Picea rubens	Spruce, red	28.4	27.2	.175	2,370	1,740
Picea sitchensis	Spruce, Sitka	28.0	27.1	.145	2,340	1,710
Pinus contorta	Pine, lodgepole	29.2	28.2	.142	2,430	1,780
Pinus echinata	Pine, shortleaf	35.7	34.6	.154	2,970	2,180
Pinus lambertiana	Pine, sugar	26.0	24.9	.162	2,170	1,590
Pinus monticola	Pine, western white	28.0	27.1	.129	2,330	1,710
Pinus palustris	Pine, longleaf	41.6	40.3	.179	3,470	2,540
Pinus ponderosa	Pine, ponderosa	28.6	27.5	.162	2,380	1,740
Pinus strobus	Pine, eastern white	25.4	24.2	.167	2,120	1,550
Pinus taeda	Pine, loblolly	36.3	35.2	.154	3,020	2,210
Pseudotsuga menziesii	Douglas-fir, Coast	34.3	33.1	.170	2,860	2,090
	Douglas-fir, Rocky Mountain type	30.5	29.2	.179	2,540	1,860

See footnotes at end of table.

Table 7.--Average weight of some North American woods under different conditions of moisture content, with adjustment factors for moisture content changes [1]--Continued

Botanical name	Common name [2]	Weight per cubic foot			Weight per 1,000 board feet (15 percent moisture content)	
		Based on weight and volume at a moisture content of 15 percent	Based on weight and volume at a moisture content of 8 percent	Factors [3] for adjusting value for each 1 percent change in moisture content	Actual [4] board feet	Dressed (1 by 8 dressed to 25/32 by 7-1/2)
		Pounds	Pounds		Pounds	Pounds
		SOFTWOODS--Continued				
Sequoia sempervirens	Redwood	28.6	27.4	0.175	2,380	1,740
Taxodium distichum	Baldcypress	32.6	31.4	.167	2,720	1,990
Thuja plicata	Redcedar, western	23.4	22.4	.137	1,950	1,430
Tsuga canadensis	Hemlock, eastern	29.0	28.0	.150	2,420	1,770
Tsuga heterophylla	Hemlock, western	29.6	28.7	.129	2,470	1,810

[1] Data from "Wood Handbook" (Appendix A).

[2] From "Check List of Native and Naturalized Trees of the United States" (Appendix A).

[3] To increase value to any desired moisture content up to 30 percent, multiply factor by difference in percentage moisture content and add; to decrease value, multiply and subtract. The factors allow for shrinkage or swelling with moisture changes.

[4] To convert pounds per actual thousand board feet (83.3 cu. ft.) into kilograms per cubic meter, divide by 52.

STORAGE AND HANDLING OF LOGS TO MINIMIZE DETERIORATION

Logs need to be stored under conditions that will prevent the occurrence of defects associated with shrinkage or attack by fungi and insects. Defects associated with shrinkage are held to a minimum during periods of precipitation and high relative humidity. Likewise, fungi and insects are inactive at low temperatures.

Logs should be taken from the woods and sawed into lumber as soon as possible, particularly during warm weather. At a small sawmill where only a few logs are accumulated, no other precautions are needed for log storage. At larger permanent sawmills, a considerable supply of logs is often kept on hand, and some precautions should be taken. Two general types of log storage, ponding and cold decking, are suitable for woods-run logs. For high-quality logs, other precautions can be taken.

POND STORAGE

A log submerged in water is protected completely from drying defects and from insect and fungus attack. Of course, some portions of most logs stored in ponds are above water (Figure 14). The above-water portions may develop drying defects, such as end checking, and they are exposed to attack by insects and stain and decay fungi if stored too long during warm weather. Frequently, logs stored in ponds are banded together (Figure 15). This method of storage increases the log-holding capacity of the pond, prevents sinker logs from sinking, and submerges more logs in each bundle when some sinkers are included. Some logs, however, may be completely above water and subject to deterioration in warm weather. The storage pond should be fresh water. Salt water may contain teredos or other marine wood borers.

COLD-DECK STORAGE

Logs in cold decks (Figure 16) may end check and be attacked by fungi and insects, especially during warm weather when higher temperatures speed up drying and fungus and insect activity. Spraying with cold water to keep them wet, especially during warm dry weather, will reduce end checking and splitting, staining, and decay. End checks and end splits in logs can also be reduced by applying a thick covering of a good end coating (Figure 17). An end coating should be highly water resistant. Thick asphalt preparations or natural gums or resins should be suitable. Specially prepared end coatings are described in U. S. Forest Products Laboratory Report No. 1435 (Appendix A). A list of United States suppliers is given in Appendix C.

Losses caused by stain and decay fungi can be reduced and often prevented by the application of chemical solutions. One spray treatment to

Figure 14.--Logs stored in a pond.

Figure 15.--Logs banded together for storage in a log pond.

Figure 16.--Cold-decked logs.

Figure 17.--Effect of end coating in preventing end checking in the right half of a sweetgum log.

control both insect and fungus damage is mix 25 gallons of 5 percent pentachlorophenol solution and 25 gallons of light petroleum oil to make 50 gallons of solution. Add 17 pounds of a 10 percent solution of gamma isomer of benzene hexachloride. Thoroughly spray the sides and ends of each log immediately after it is cut in the woods. This treatment can be applied with an ordinary hand-operated garden sprayer. In case the chemical solutions available commercially are more concentrated than those mentioned above, the proportions for making the spray mixture should be changed in accordance with directions furnished by the manufacturer.

During storage, chemical changes may occur in the sap of logs and cause stain as the wood dries. Some of the pines are particularly susceptible to a stain that ranges from light to dark brown in color. Much staining, however, can be avoided by sawing the logs into lumber without delay and promptly drying the lumber.

AIR DRYING OF LUMBER

Air drying is accomplished by exposing lumber to the outdoor atmosphere in a drying yard or shed. Drying occurs except when the relative humidity of the air is excessively high. Air drying is the simplest, and in many cases the cheapest, drying process. Sometimes the object in air drying is to completely dry the lumber to a moisture content consistent with climatological conditions. Other times the object is to dry the wood just enough so that it is ready for shipment or is ready for kiln drying. In all cases, the aim is to dry the lumber in the shortest possible time, with the least deterioration.

Applying the features of good air-drying practice to the yard-drying operation will result in the shortest drying time with a minimum of drying defects. These features consist mainly of a favorable location for exposing the lumber to a good drying atmosphere and piling the lumber so that air circulates around each board. Most of this section deals with yard drying, but the general facts of good air drying apply in a shed as well as in the open.

The best method of piling lumber for fast drying, with the least amount of checking and warping, is flat piling. Easy drying woods that do not check badly can be piled by the simple methods of end racking, end piling, or crib piling. These methods cause fast drying that helps to prevent decay and sapwood stains. But in general these simple methods allow more warping, end splitting, and staining at crossings. After the first few days of drying, the lumber should be repiled in flat piles.

The general information on air-drying yards applies to all types of piling. More details are given on flat piling, but information on end racking, end piling, and crib piling is included.

YARD SITE

The air-drying yard is preferably located close to the plant producing the lumber in order to reduce the hauling distance between the plant and the yard. The best location is on high ground that is reasonably level, well drained, and not surrounded by tall trees or buildings.

SITE PREPARATION

Grading and Drainage

The yard should be graded so that it is level or sloping slightly, avoiding hollows that collect and hold rainwater. Such wet spots interfere with lumber drying and sometimes with the movement of vehicles. If the soil is not light and porous, it is often necessary to provide drainage ditches and culverts. The ground occupied by the lumber piles should be graded to drain into the ditches. Flat piles can be sloped slightly toward the drainage ditches to encourage water runoff. The proper grading and draining of an area to be occupied by an air-drying yard provide an even surface on which to construct roadways, alleys, and pile foundations.

Surfacing and Paving

When the roadways or alleys of a yard are surfaced or paved, it helps transportation and provides better working conditions. Surfacing or paving the entire surface of a yard keeps down vegetation and promotes air movement through the yard. Portions of a few yards have been paved with asphalt for the additional purpose of absorbing more heat from the sun. It is reported that the lumber dries more rapidly in these areas than in the rest of the yard.

SANITATION AND UPKEEP

Any air-drying yard should be kept clean. Vegetation or accumulation of such debris as broken piling sticks and boards or timbers from old pile foundations interfere with the movement of air over the ground surface. Vegetation growing close to the lumber piles may prevent air from passing out from below the bottoms of the piles, or even be tall enough to interfere with the circulation of air through the lower courses of lumber. If the vegetation dies and becomes dry, it may contribute to the starting and spreading of fires. Vegetation can be controlled by mowing, grazing, or the use of weed killers. Common salt or crude oil also kills or retards the growth of vegetation. Debris, in the form of old pieces of wood lying on the ground, becomes infected with stain and decay fungi, the spores of which may infect green lumber that is brought into the yard. Debris should be hauled away and burned.

The yard should be kept in good condition. If the surface of the driveways or alleys is in good repair, it is easier and more convenient to transport lumber. Decayed and stained timbers of the pile foundation should be removed and replaced with new ones of a decay-resistant species or of preservative-treated material.

When piles are taken down, the stickers should be carefully set aside in a pile or rack and protected from precipitation when they are not in use. The practice of throwing stickers in rough piles in the spaces between the lumber piles or standing them up against adjoining piles is poor because the stickers obstruct air movement, are exposed to wetting by rain and ground dampness, and frequently get broken.

YARD LAYOUT

Most yard layouts are rectangular, with definite lateral spaces between piles, rows of piles, alleys, or roadways (Figure 18). The yard layout should facilitate the transporting and piling of lumber and the movement of air.

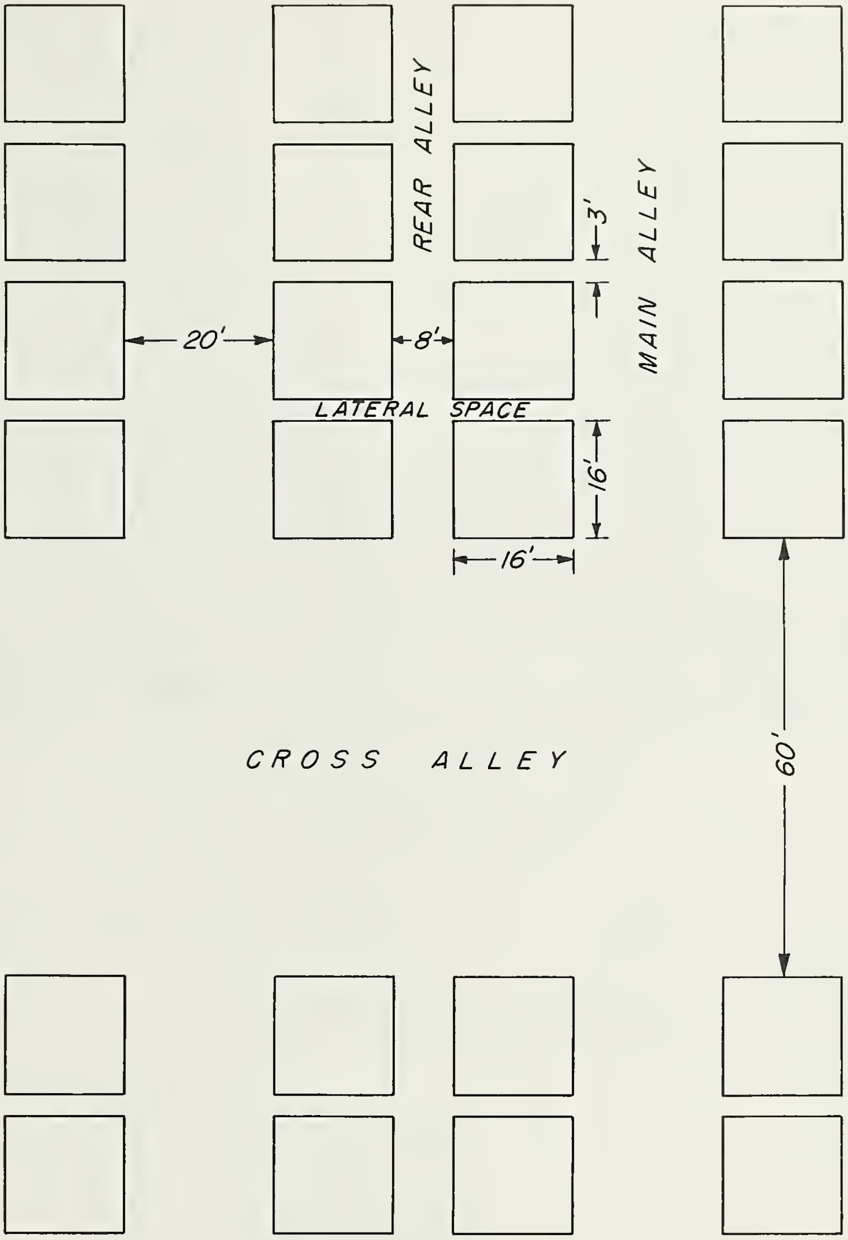


Figure 18.--Layout of a small portion of an air-drying yard.

Alleys

Alleys are generally classified as main, cross, and rear. Main alleys (Figure 19) are generally 16 to 20 feet wide. They serve as routes of transportation and as working areas from which to build the lumber piles. The orientation of these alleys usually is not important if they run straight through the entire yard and are open at the ends.

Figure 19.--Main alley in a yard of flat piles.

Pile Orientation

The direction in which the individual lumber piles are placed depends mainly on the direction of the sun, ease of piling, and drainage. The direction of prevailing wind is of little importance, because the wind does not pass directly through any piles except those on the windward edge of the yard.

When the sun shines directly on the ends of the boards, some end checking is likely to occur. If flat piles run north and south, one end is exposed to the midday sun. By placing the piles east and west, the exposure of the end is only to early morning or late afternoon sun. If it becomes necessary to run the piles north and south, the thicker lumber, which is more likely to end check, could be placed in the piles whose fronts are toward the sun. The forward pitch of the pile and the overhanging roof will afford some protection.

Piling so that the fronts of the piles face the main alleys affords easy handling and aids the drainage of rain into the rear alleys.

Crib piles require no special orientation. End racks and end piles are relatively long types of piles that should be built parallel to the main alleys for convenience of handling.

Figure 20.--Rear alley of a yard of handstacked piles, showing good drainage trough and generally good sanitation.

With the proper arrangement of alleys and spaces between piles, adequate air movement is assured, regardless of pile orientation or prevailing wind direction.

Pile Spacing

The piles in the rows along both sides of the main alleys should be separated so that there are spaces between them. These spaces contribute to the general air movement through the yard and bring air to the sides of the lumber piles. These spaces should be about 3 feet. They can be adjusted according to the weather and the item that is being piled for drying. During damp seasons, and particularly where stain is to be avoided, the width of these spaces can be increased; during the seasons of dry weather, and particularly where checking is to be avoided, their width can be decreased.

Pile Width

The width of a lumber pile, combined with a fixed height, limits the amount of lumber that a pile can hold and determines the time required to build the pile. Width also has an important effect on the rate of drying. Generally, narrow piles will dry more rapidly than wide piles. In the United States, piles of softwood lumber are often 16 feet wide, while piles of hardwood lumber are generally narrower, sometimes only 6 feet wide. In general, a 6- to 10-foot width is best for both types of wood.

Where special stickers are used, the width of the piles can be adjusted according to the climatological conditions and the drying characteristics of the lumber. Sometimes wide piles are built because freshly cut boards are used in place of stickers. This is bad practice because stain and decay can occur where two wet boards touch each other. Also, the wide piles dry the lumber too slowly. The width of the lumber piles has an influence on the yard layout, because narrow piles require less space between piles than wider piles.

PILE FOUNDATIONS

For Flat Piles

A flat pile foundation supports the lumber and provides clearance between the lumber and the ground to exhaust the moist air that moves down through the lumber. Proper foundation design and proper materials will give long service life and low maintenance costs. Wood in pile foundations should be from heartwood of decay-resistant species or be pressure treated with a preservative.

A pile foundation may consist of mudsills or sleepers, posts or piers, stringers, and crossbeams (Figure 21). Mudsills or sleepers rest upon the surface of the ground, or slightly below the surface, and support the piers or posts. The piers or posts may be round sections of logs, sections of timbers, concrete, cement building blocks, or bricks. Square wooden posts should be about 6 by 6 inches in dimension, and sections of logs should be 6 to 8 inches in diameter. Where the entire surface of the yard is paved with concrete or asphalt, sleepers are unnecessary, and the posts or piers usually rest directly on the pavement. Diagonal braces are needed to prevent lateral tipping. Posts or piers may also be set into the ground. In cold countries such posts should extend below the frostline.

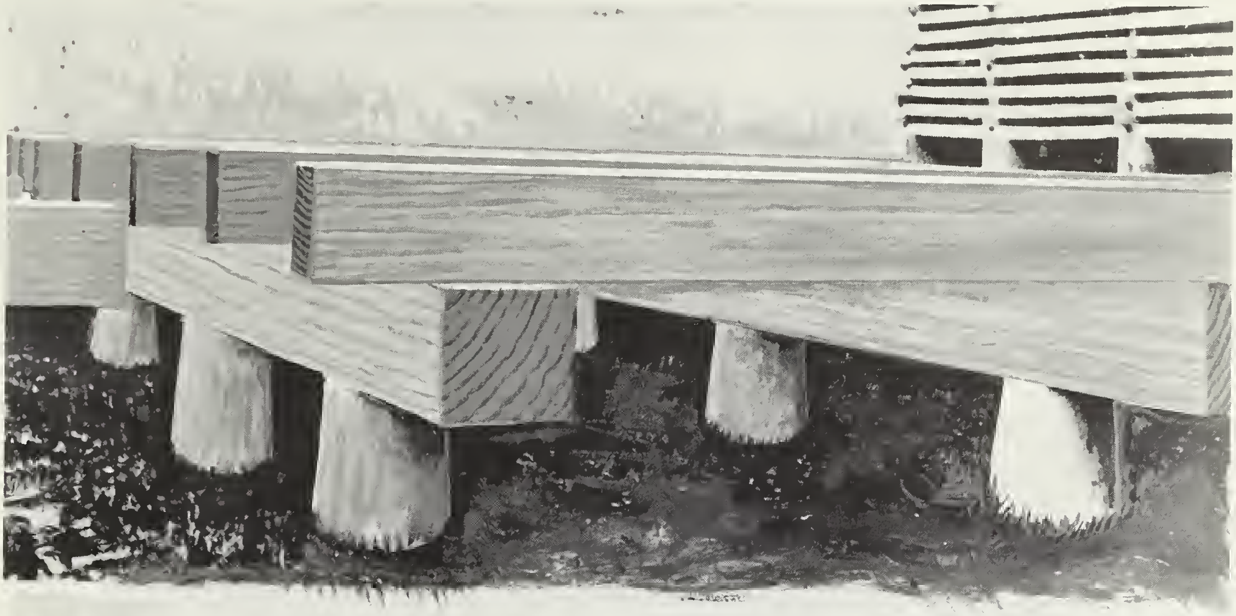


Figure 21.--A good pile foundation consisting of posts, stringers, and crossbeams, with slope from front to rear.

Stringers run lengthwise of the pile and rest on the tops of the posts or piers. Stringers consist of 6- by 8-inch timbers placed on edge. Stringers for 16-foot lumber are generally supported by three posts. A lumber pile 6 feet wide should have two stringers in the foundation. For piles of from 7 to 12 feet, three stringers are required and above 12 feet four stringers. The crossbeams are placed on the stringers and are spaced from 18 inches to 4 feet apart, to correspond to the sticker spacing. Sometimes stringers are not used, and the crossbeams rest directly upon the tops of the piers or posts. Crossbeams consist of timbers 4 by 6 inches in dimension, placed on edge.

Flat pile foundations should slope downward from the front to the rear end. The top of the foundation at the rear or lowest point should be 18 inches above the ground surface. Going toward the front end, for each 12 feet of length the foundation should be 1 foot higher. Thus for a 16-foot pile the front end should be 34 inches above the ground (Figure 21).

Pile foundations should not be made of solid cribs of planks or timbers laid on the ground. This type of construction tends to restrict air movement beneath the lumber piles.

For Crib, Rack, and End Piling

Proper support of the lumber and protection from the moisture in or on top of the ground are as important for crib, rack, and end piling as for flat piling. Raising of the bottoms of the piles 18 inches above the ground for air movement into the yard spaces also would be desirable for crib and end piling.

In crib piling, separate piles for each length of lumber are made by cribbing tiers of material to form a triangle. Each side of the triangle may consist of single pieces if the material is wide. If the pieces are narrow, two or three may be used per side. The support for each corner of the triangle should be of stone, concrete, decay-resistant heartwood, or preservative-treated sapwood. For sides of single pieces, blocks or stones should be approximately 12 by 12 inches. Posts to be set in the ground should be 6 to 8 inches in diameter. Figure 22 shows short 6- by 8-inch timbers laid flat or on edge to support a crib pile of 2 by 4's, with three pieces forming each side.

Figure 22. --Crib piling of 2 by 4's.

Decay-resistant mudsills have particular value under timbers or blocks on wet ground. The supports should be so spaced that the boards will cross directly above these support points. For short-length lumber, this crossing is at the ends of the boards. For longer lumber, the boards may cross 1 to 2 feet back from the ends. The tops of the supports for all three corners should be about at the same level.

In end racking, the boards are leaned against a supporting frame (Figure 23). The frame should be strong enough to support the upper ends of the boards and braced in both directions to avoid tipping or collapse. The uprights should be about 6 inches thick. The lower ends of the boards are supported at least 6 inches above the ground by hewed poles, timbers, or boards on blocks. All wood in contact with the ground or not more than 2 feet above the ground should be of decay-resistant heartwood or preservative-treated wood. For long lumber, middle supports are desirable halfway between the base and the ridgepole.

Figure 23. --End racking.

End piling is like tilting a flat pile until the boards are almost vertical (Figure 24). The bottom ends of the boards should be supported above the ground on a strong, wood platform. This can be made of dry lumber or allowed to dry in place before use. A platform height of 18 inches above the ground is desirable, but a lower height of 3 to 6 inches can be used. When separate platforms are used for narrow piles, the floor boards can be placed close together. When a larger platform is used for several piles, as in Figure 24, spaces should be left between the boards.

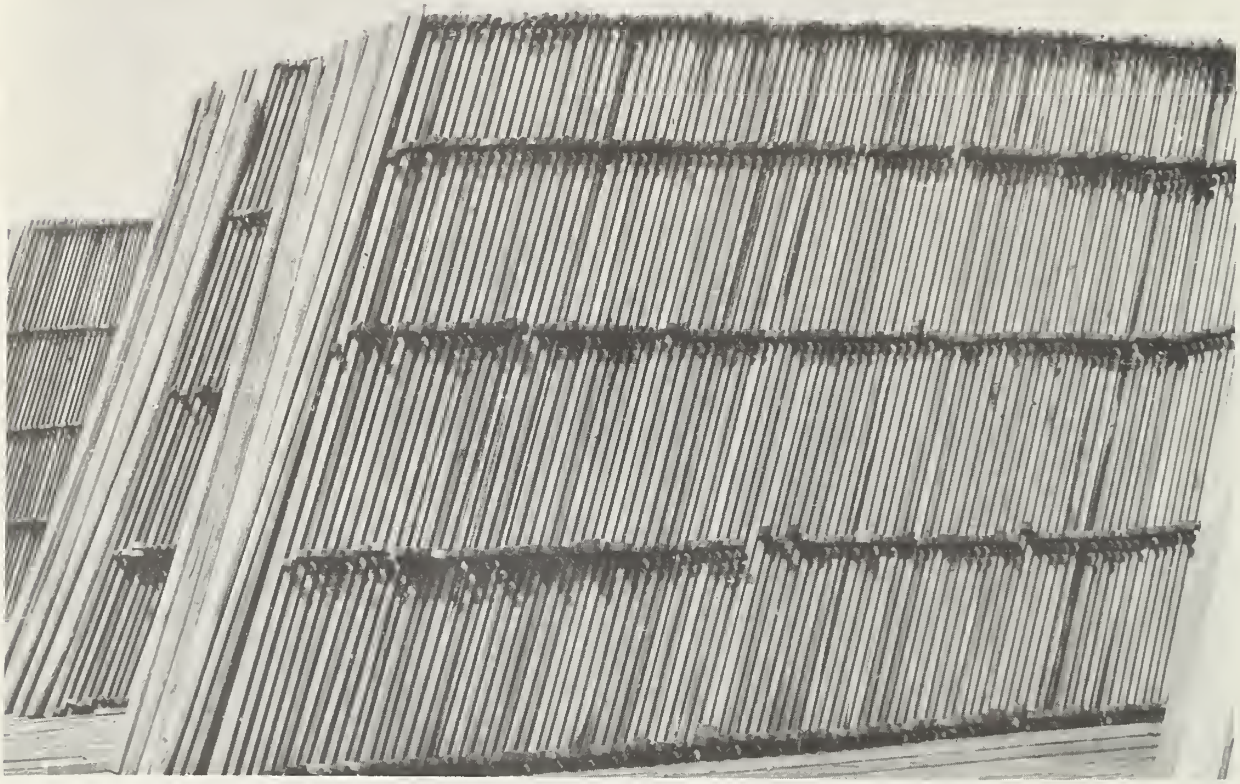


Figure 24. --End-piled lumber resting on a wood platform.

At the starting end of each pile an inclined framework is built of sturdy poles or timbers about 6 inches thick. This should be 8 to 12 feet high. The bottom of the inclined frame should be about 4 or 5 feet out from the center supports. The frame needs crossbeams every 4 feet to support the rows of stickers, as well as a cap plank. It also must be strongly braced to withstand the weight of the long pile of leaning lumber, or be a double frame from which lumber can be piled in both directions. Short sticker supports are nailed to the inclined framework to start the courses of stickers over the crossbeams. All wood contacting the ground or within 2 feet of it should be of decay-resistant heartwood or preservative-treated material.

PROTECTION OF FRESHLY SAWED LUMBER

It is important that lumber be protected from the time it leaves the sawmill until it can be transported to the yard and built into a pile. Unless the weather is cold, freshly sawed lumber is subject to attack by fungi and insects and is susceptible to checking and splitting if exposed to direct sunshine. Protection against attack by fungi or insects can be acquired by dipping the green lumber in a solution of toxic chemicals (Figures 25 and 26). Prompt piling of the lumber for air drying also makes attack by fungi and some types of insects less probable. Protection from direct sunshine can be accomplished by placing a roof over the area used to sort and accumulate the freshly sawed lumber. Moisture-resistant end coatings can be applied at this stage of the manufacturing process to protect against end checking and end splitting during handling and subsequent drying. Lists of suppliers of toxic dips are given in Appendix D.

Figure 25.--Hand-dipping vat and drain board for applying antistain solution.

Figure 26.--Automatic dipping vat placed just ahead of the green chain.

SORTING

After freshly sawed lumber has passed through the sawmill, it should be sorted on the basis of species, thickness, and quality, and assembled into small piles for transportation to the air-drying yard. If the mill is large enough to have a green chain, the lumber is pulled from it into separate piles. A smaller mill can use a sorting table. The small piles of lumber may be placed in bins or bays alongside the green chain or loaded directly on dollies, wagons, or trucks (Figure 27).

Figure 27.--A simple wagon for hauling green lumber to the yard.

From the standpoint of stacking and control of warping, it is essential that lumber be sorted on the basis of thickness. Sorting by length and width also simplifies piling. Sorting on the basis of species tends to increase the efficiency of the air-drying operation, because species may differ in their drying characteristics. On the same basis, sorting within a single species on the basis of heartwood and sapwood also contributes to drying efficiency. Sorting has practical limitations, however, because the more complete the sorting, the smaller the amount of material in any single category. An item that accumulates slowly is difficult to handle in the piling operation because of the length of time required to complete the pile. The degree of sorting that is feasible is related to the total production of the mill, the number of species cut, and the number of different thicknesses.

TRANSPORTING LUMBER TO THE YARD

The lumber that has been collected into small solid piles at the mill should be transported promptly to the yard for piling. The loads may be hauled on small wheeled vehicles pulled by men, draft animals, or tractors, using the roadways or alleys provided in the yard layout. Motor-driven trucks, or trucks and trailers, may also be used if they are available. When the lumber is brought to the spot in the drying yard where it is to be piled, it is either dumped on the ground or left on the dolly, wagon, or trailer during the piling. When the roadways are paved or surfaced with gravel, crushed rock, or decay-resistant planking, transportation is easier.

Transportation of green lumber is one of the hardest and most time-consuming jobs at a sawmill. Special mechanical handling equipment such as fork-lift trucks and straddle carriers are used in the United States. For small mills, special fork-lift units are available for mounting on a regular motor truck (Figure 28).

Figure 28. --Ordinary motor truck converted to fork lift.

PILING

Lumber is built into several types of piles for air drying. In most types the boards are placed flatwise, or nearly flatwise, but in some types boards are placed nearly endwise. The most common and best type consists of layers of boards laid flatwise, separated by stickers or crossers. In such a pile each board carries its share of the weight of the pile above it. This tends to restrain warping. If other types of piling, such as crib piling, end racking, or end piling, are used to obtain fast drying at the start, repiling in flat piles may be necessary later to prevent excessive warping.

Crib Piling, End Racking, and End Piling

In crib piling the first board rests directly on two of the three supports. One end of the second board crosses the first above one support and the other end rests on the third support. The third board closes the triangle. In succeeding courses, this crib work is carried to a height convenient for one-man stacking. The boards should cross directly above the supports.

One advantage of crib piling is that it can be done by one man. A disadvantage is that it requires an excessive amount of yard space to pile a large amount of lumber. It encourages rapid drying, except at the spots where the planks or boards cross. The retarded drying in these areas makes them susceptible to both fungus and chemical stain. Sap stain caused by fungi may be prevented by application of a toxic chemical. In a crib pile no stickers are used and the boards are likely to warp because of the long unsupported spans. Crib piles are seldom roofed, and the exposure of the boards to the elements is likely to cause checking and warping.

In end racking, individual boards are crossed over a supporting framework with the board edges in contact with the top ridgepole of the frame. Crossing the boards near the top separates the boards by a space equal to the thickness of the lumber. Care should be used to place the lower ends of each board securely on the lower support with about the same space between them.

End racking, even more than end piling, promotes rapid drying. End racking also can be done by one man. Disadvantages of end racking are the tendency of the boards to stain where they cross, and the tendency to warp, since no stickers are used and there is no weight on the faces of the boards. There also is a likelihood that the upper ends of the boards will check and split where they are exposed to the weather. Less material is damaged by stain and decay if the boards are crossed at the top in the inverted V-type of piling than if they are crossed at a lower point to form an X.

End piling (Figure 24) is started by placing the first course of boards against an inclined framework. A space of 4 to 8 inches can be left between boards if the fastest drying is wanted. Temporary sticker supports can be nailed to the side of the pile. As the pile grows, these can be removed and nailed further along. Stickers that are slightly longer than the width of the pile are placed on the sticker supports. Additional courses of boards and stickers are placed as the lumber comes from the sawmill. Each pile should be limited to a length of about 40 feet, since the driest material is on the starting end of the pile and the material that must be unpiled first will be the wettest.

End piling induces rapid drying. Another advantage is that it can be done by one man. The disadvantages are the exposure of the upper end of the boards to sunshine and wetting, with the consequent tendency to check and split, and a greater tendency for the boards to warp because there is little weight placed upon them. Also, the lower ends of the boards may be considerably wetter than the upper parts at the end of the drying period.

Building a Flat Pile

The important facts about flat piling softwoods, or easy drying hardwoods, of uniform length for rapid and uniform air drying are shown in Figure 29. More details on the supporting foundation are given under "Pile Foundations." Although the pile is generally flat, it slopes slightly from the front to back to drain rainwater out of the pile toward drainage ways.

Similar details for flat piling slower drying hardwoods are shown in Figure 30. The use of closer sticker spacing, narrower flues, and less clearance between lumber and roof helps to reduce warping and surface checking.

The lumber pile is started by placing the first course or layer of boards upon the crossbeams of the pile foundation, or upon stickers placed upon the crossbeams. Stickers are laid on the first course of boards and the process is repeated. At least two men are needed to build a pile. The piling is done while standing and walking upon the lumber pile. As the pile grows in height, one of the two men remains on the lumber pile, the other man on the ground. The boards are up-ended and pushed up by the man below and pulled up by the man on the pile.

The height limit, including the height of the pile foundation, is 12 to 15 feet with such a method. The pile may be built higher by using elevating devices or temporary scaffolding and a larger crew. Pile height probably should not exceed 23 feet, since the lumber in the lower parts of any yard pile tends to dry more slowly than that in the upper parts. The taller the pile, the greater is this difference. The pile height also has an effect on yard layout in that tall piles require wider spacing than shorter piles. The effect of pile height as well as pile width on drying rate varies with the character of the pile itself. The more open the pile, the less is the effect of pile height or pile width on the drying rate.

Tall piles naturally weigh more than shorter ones of the same width and length. This weight imposes a load on the bottom part of the pile. This load is borne by the stickers and those portions of the boards in contact with them. The load may crush the stickers or impress them into the faces of the boards. Therefore, there should be more or wider stickers in a tall pile than in a low pile. If the tiers of stickers are not in alinement, then the load is imposed on the spans of the boards between the stickers. This causes bowing of the lumber and may cause permanent sagging or breakage.

Box piling.--Box piling is a term that is used to describe a method of flat piling lumber of mixed lengths. In box piling, the edges of the pile are

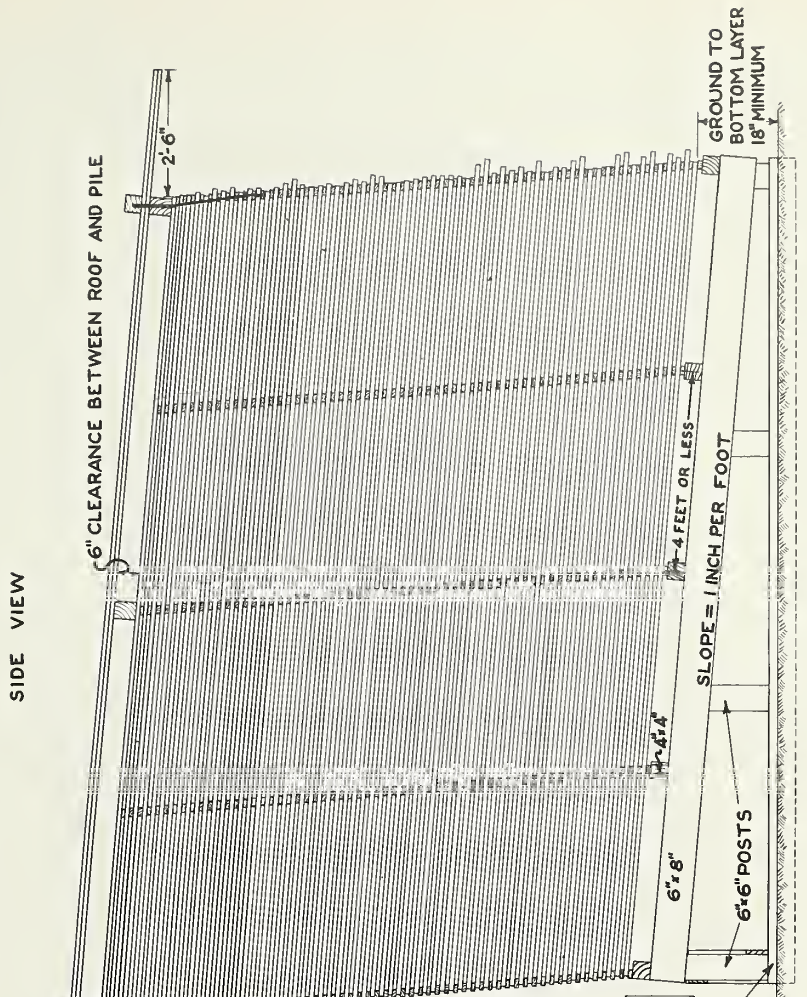


Figure 29.--Flat piling method for piling softwoods in a sloped and pitched pile for rapid and uniform air drying.

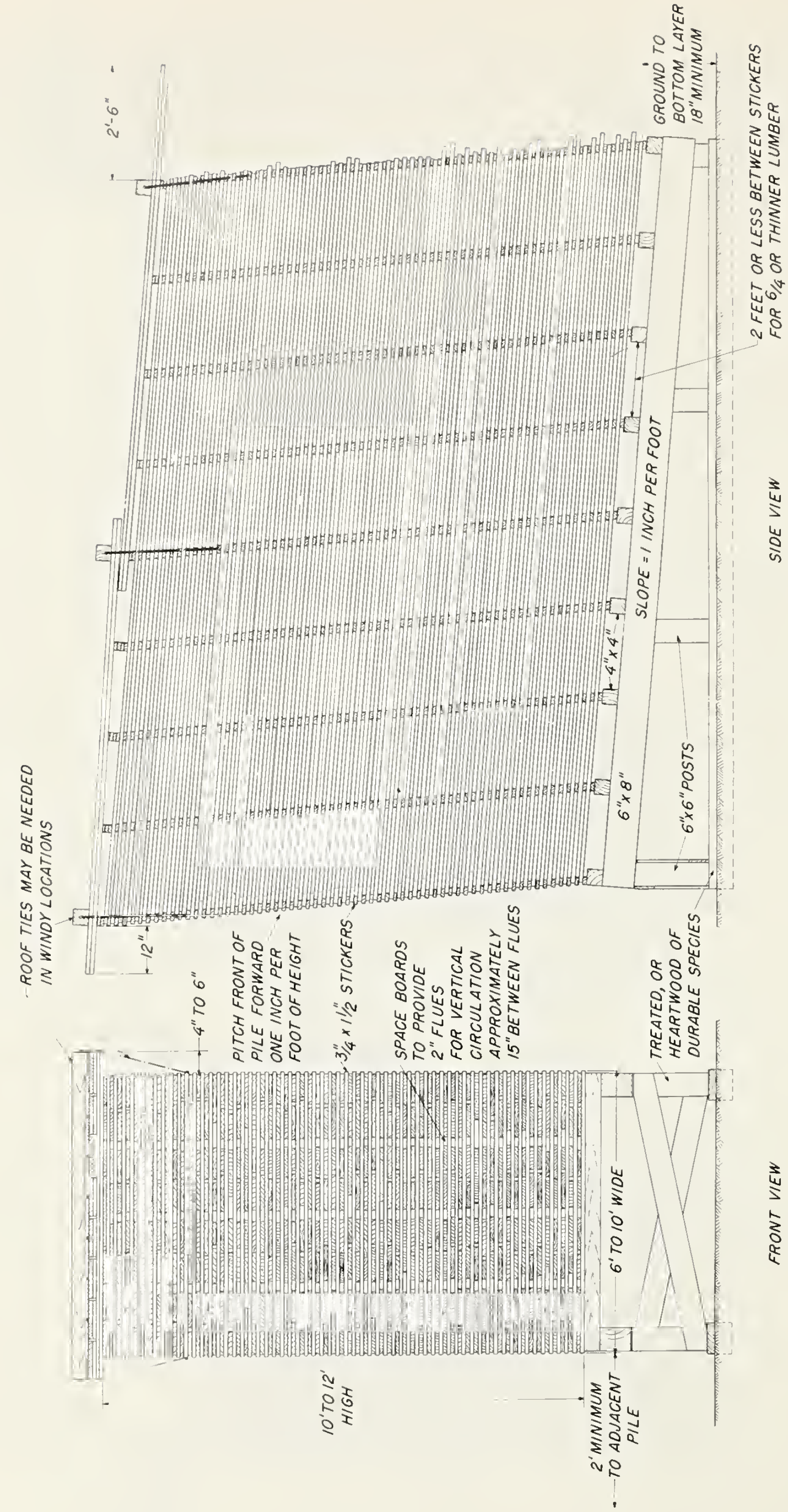


Figure 30.--Flat piling method for piling hardwoods in a sloped and pitched pile for uniform drying with a minimum of seasoning defects.

made up of boards of the longest length. If there are more than enough long boards to make up the edges, additional tiers of long boards are distributed uniformly across the width. The spaces between the long boards are filled with shorter boards. The arrangement of the boards in one course or layer of a box pile is shown in Figure 31. A box pile has no projecting board ends at the rear, since the length of the pile is determined by the length of the longest boards. If there are not enough long boards for the outer edges of the piles, a true box pile cannot be built. If there are, however, enough short boards half as long as the long boards, then practically the same result can be obtained by end-to-end pairs of these short boards in the outer edges. A true box pile cannot be built if there are a few excessively long boards in the batch of lumber. If these excessively long boards are distributed throughout the height of the pile, their ends will project at the rear. Such boards will warp and check badly. If it is practical to sort out these boards before the pile is built, they should be placed in the lower portions of the pile.

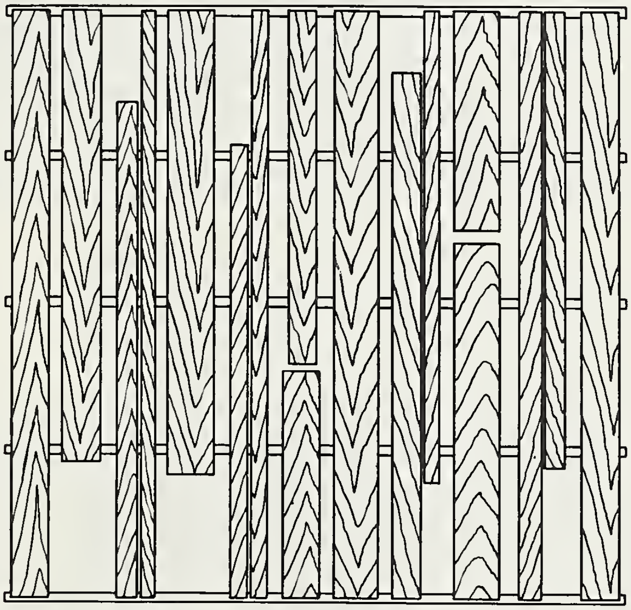


Figure 31.--Arrangement of boards in a course or layer of a box pile.

Edge piling.--Lumber that is relatively thick in comparison with its width is sometimes piled on edge (Figure 32). Edge piling requires that the lumber be of one width. Stickers are used with edge piling as they are with other forms of flat piling. When lumber is piled on edge, spaces are left between individual pieces to provide vertical passageways for the downward movement of air across the broad faces of the pieces. This method tends to restrain crooking.

Board Spacing

The boards in a course of a flat pile should be placed so that there are spaces between the edges of individual boards (Figure 33), or the boards may

Figure 32.--Edge-piling of 2 by 4's, with outer tiers placed flat for stability.

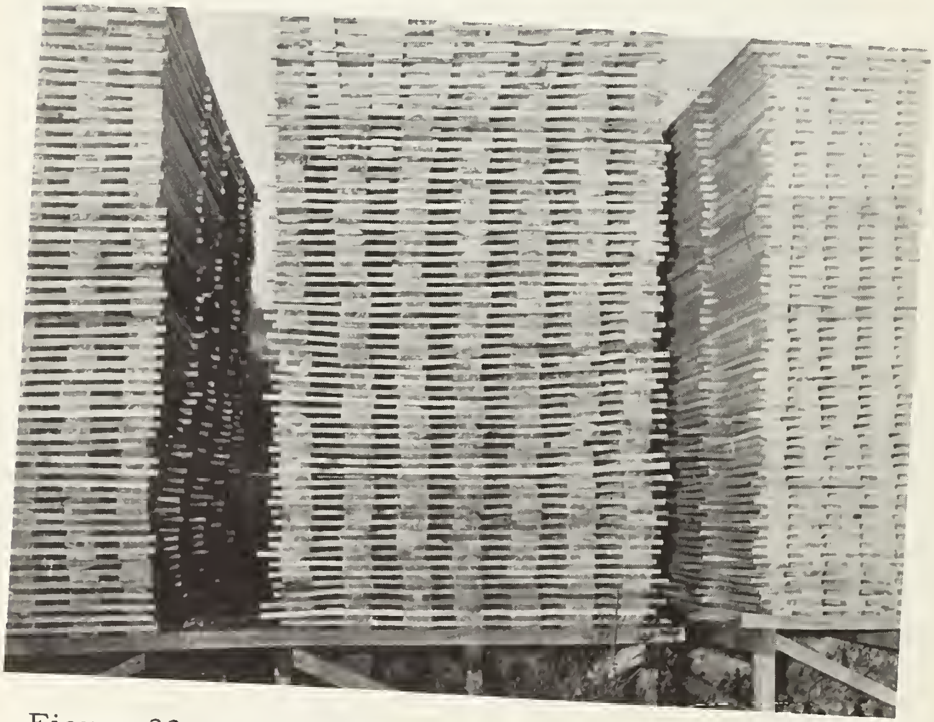


Figure 33.--Vertical spaces between individual boards in a flat pile.

be grouped and the spaces left between the groups. The spaces left between the groups of boards should result in vertical openings that are called flues or chimneys. When these openings are 6 inches or less in width, they are called flues. When wider, they are called chimneys.

Chimneys and flues provide passageways for the movement of air. A downward movement takes place in these flues or chimneys because the air within a lumber pile becomes cooled and denser as water evaporates from the lumber. The downward movement of air in these vertical passageways brings in fresh and drier air at the top and sides of the pile. After the air has passed downward to the space between the pile and the ground, it should be free to pass from beneath the pile. A pile foundation of open construction on a clean ground surface facilitates the exhaustion of air from beneath the pile.

There is no fixed rule about the raio of flue or chimney width to the width of the pile. A large ratio of flue width to pile width is used where rapid drying is desired. The minimum ratio of flue width to pile width is probably about 1 to 5. A large central chimney stimulates drying if piles more than 10 feet wide are used. It is advantageous to have these flues and chimneys straight-sided by having the edges of the boards in vertical alinement. Chimneys, however, are sometimes tapered, being wider at the bottom than at the top (Figure 34).

Figure 34.--A tapered chimney in a handstacked pile of random width lumber.

Stickers

Stickers, or crossers as they are sometimes called, are an important item in air drying. They perform several important functions. They separate the courses or layers of lumber, permitting air to pass over the boards. Each sticker carries its share of the weight of the pile. The pressure exerted on the boards by the stickers tends to restrain warping, but it also tends to resist shrinkage in width. This may cause splits adjacent to the sticker. The stickers at the ends of a pile may reduce end checking and splitting. The type of stickers that are used also affects sticker staining.

In the United States, stickers for piling hardwoods are generally made from 1-inch lumber, either rough or dressed. Their width is about 1 to 2 inches. Stickers for softwoods are generally about 4 inches wide, and are also made from 1-inch stock, either rough or dressed. Thicker stickers are used sometimes. Edgings of irregular and varying widths are often used for stickers. They should, however, be of a uniform thickness.

Sometimes the narrower boards of the lumber itself are used as stickers. When they are, the pile is said to be self-stickered. As such a pile is taken down, these stickers are put in with the rest of the boards. This is generally a bad practice, for both the sticker-board and the lumber at the area of contact dry slowly. The contact areas may also stain badly or even decay.

Stickers are generally made from air-dry lumber that is available at the mill. Heartwood is better than sapwood, because sapwood stickers may become infected with stain or decay fungi. These, in turn, infect freshly cut lumber that comes in contact with them. Stickers cut from green boards should be air dried before use. Green stickers are likely to cause sap or chemical stain in the boards. When edgings are used, it is wise to saw them to uniform 1- to 4-inch widths.

The number and position of the stickers often have an important bearing on the development of drying defects. The number of stickers varies with the species, thickness, type, and grade of lumber. Lumber from a species that tends to warp needs more stickers than lumber from other species. Thin lumber needs more stickers than thick lumber. Lumber that is susceptible to staining should be piled with a minimum number of dry and narrow stickers. High-quality lumber should be piled with more stickers than low-quality lumber of the same species.

Since stickers help support the pile, they should be in alinement, either vertically or following the pitch in a sloped and pitched pile (Figures 29 and 30). If they are not in good alinement, some of the weight of the pile will be imposed on the boards themselves in between the stickers. Sagging and eventual warping will result. The use of a sticker guide is the best way to assure good alinement. Figure 35 shows a drawing of a sticker guide that fastens to the side of the pile and can be moved upward as the pile increases in height.

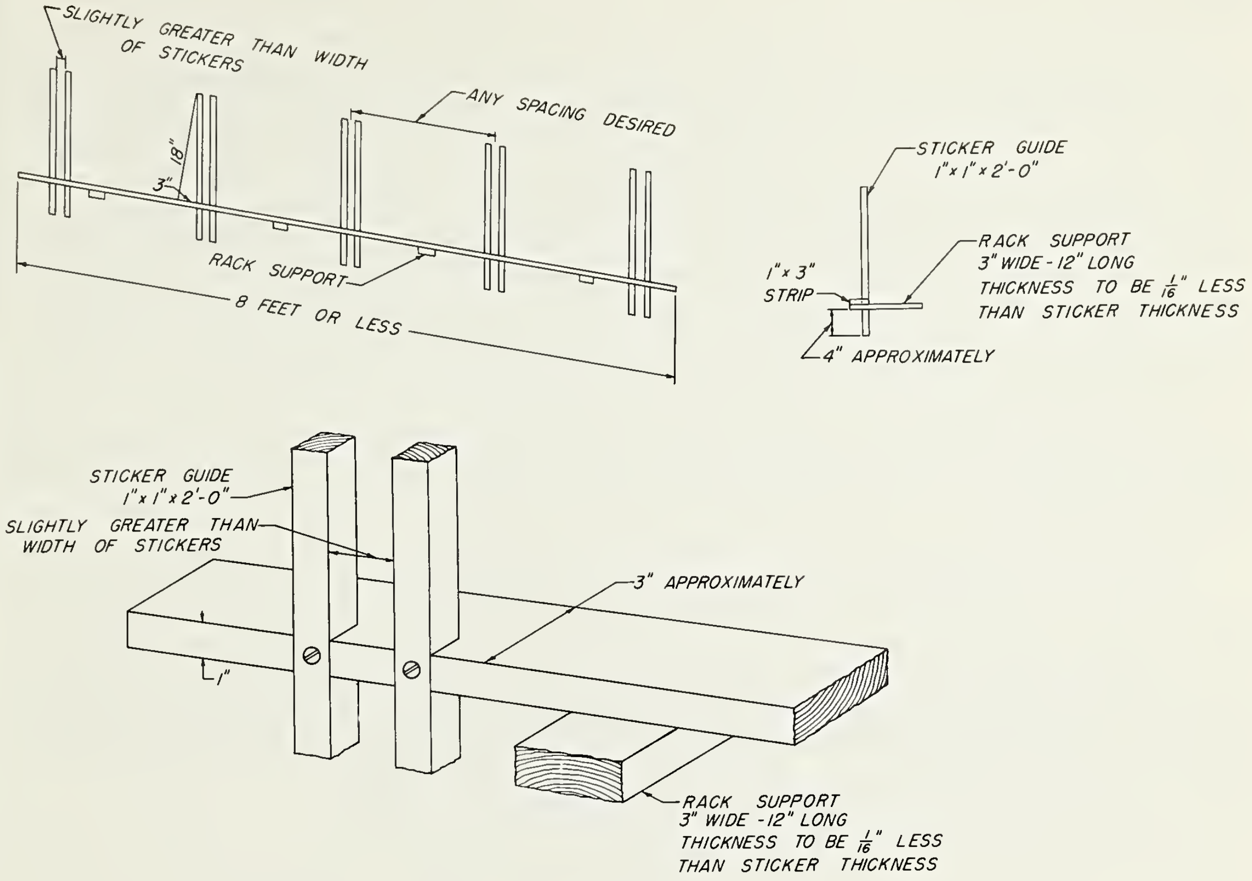


Figure 35. --Sticker guide for flat piling. The guide is attached to one side of the pile by inserting the rack supports between the courses of lumber.

The position of the stickers at the ends of the pile may have an effect on end checking and splitting. Placing the stickers flush with the ends of the boards reduces these defects. Stickers that project slightly beyond the ends of the boards tend to shield the ends from sunshine and wetting. They also retard drying somewhat by interfering with the flow of air over the board ends. Projecting stickers, therefore, may reduce end checking. This in turn reduces splitting because splits often develop from end checks. Where the stickers are placed several inches back from the board ends, end checking and splitting are prevalent. The splits generally run to the stickers.

Stickers represent an appreciable capital investment. It pays to take care of them. Stickers may be broken by being thrown down, stepped upon, or run over. In a poor pile where stickers are subjected to a load beyond their capacity they break or warp. Stickers also may warp if they are exposed to the weather. Furthermore, stickers may become decayed or stained if they are left lying on the ground or exposed to rain. When a yard pile is taken down, the stickers should be placed in a pile or rack supported above the surface of the ground and protected from the weather.

Pile Roofs

Lumber piled for air drying should be protected from the weather. The boards in the upper course of a pile that is not roofed will check, split, and warp under the influence of sunshine and wetting. The boards immediately below the top course will be exposed to wetting, particularly after the boards of the top course have shrunk and warped. In the early stages of drying, wetting merely retards drying. During the later stages, wetting may induce checking, increase the size of checks already present, or encourage staining, particularly where the water collects and remains between the boards and the stickers. Numerous economic studies have proved that it pays to roof yard piles of all but the lowest grades of lumber.

If considerable time is required to build a pile, a temporary roof should be used to protect those boards that happen to be in the top course at any time when work stops.

Simple but efficient pile roofs are shown in Figures 29 and 30. For maximum protection, the roof should project beyond the ends and sides of the piles. For a sloped pile, the roof should project about 1 foot at the front, 2-1/2 feet at the rear, and 6 inches at the sides. The roof should be pitched so that the water will drain to the rear and drip off. The roof extension at the rear of the pile generally allows the drip to fall free. If the roof is not tight, the pitch should be increased to about 1 in 9 rather than 1 in 12. A method of increasing the pitch is shown in Figure 36.

Figure 36.--Loose board roof on a sloped and pitched pile.

There are numerous types of pile roofs. Boards of poor quality are often used to construct a loose board roof. The boards may be kept in the yard and used many times, or they may be sold when the lumber pile is taken down. The most efficient roof is made by laying the boards in double layer and double length (Figures 30 and 36).

To build such a roof, two cross pieces are laid on the top course of boards on the rear half of the lumber pile. One cross piece is placed near the center of the pile from end to end, the other is placed near the rear end. These cross pieces should raise the roof 4 to 6 inches above the top course of boards. Use only 2- to 4-inch clearance for thick or dense hardwoods subject to bad checking. A single layer of roof boards is placed upon these two cross pieces with spaces between their edges. A second layer of roof boards is then placed over the openings in the first layer. The rear end of the roof boards should project 2 to 2-1/2 feet beyond the rear end of the pile. A cross piece is next placed at the front end of the lumber pile. This cross piece should be high enough so that the front half of the roof will have the same pitch as the rear half. The roof boards of the front half of the roof will overlap those of the rear half.

Any pile roof should be secured against being blown off by the wind. Three cross pieces should be placed on top of the roof, and these cross pieces should be fastened to the pile by ropes, wires, or some other means.

Materials such as building paper or roofing can be used to roof the piles. These materials may be fastened on a framework to form roof panels, or laid directly on the top course of lumber. Panel-type roofs can be anchored to the pile the same as the other types. When the material is laid directly on the top course of lumber, low quality boards or stones should be laid on top to hold the paper on the pile. Sheets of corrugated metal or cement-board may be used in various ways to form pile roofs. The sheets may be placed on supporting members and lapped like shingles or fastened to light frameworks to form roof panels.

Thatched roofs can also be used. A light framework can be covered with straw, leaves, bark, or other available material. It is probably easiest to pitch a thatched roof from the center line of the pile toward both sides. With this kind of slope, the pile itself can be built without slope from front to rear or pitch to the front. A thatched roof with enough overhang at both ends and sides should afford good protection. The thatched roof might be built on the pile after it is completed, or made of sections that could be assembled on the pile. Such sections can be used repeatedly until worn out or damaged. As with other roofs, a thatched roof needs to be fastened to the pile to avoid being blown off by wind.

Drip Boards and Sun Shields

Drip boards and sun shields may be considered in the same category as pile roofs because their function is to protect the lumber from the weather. In a tall pile that is sloped and pitched, drip boards replace stickers at intervals in the rear end of the pile (Figure 37). The drip boards catch rain that may be driven against the rear end of the pile and cause it to drip from board to board and eventually reach the ground without running into the pile.

Figure 37.--Drip boards at the rear end of a pile.

Sun shields may be placed at the pile end that faces the sun when the pile contains valuable thick stock. Near midday the ends of the boards in such a pile are likely to be exposed to direct sunshine. Such sun shields help to minimize end checking. The boards of the shield may be attached to the end of the pile or to a special portable framework (Figure 38).

SHEDS

Piling lumber for air drying within an open shed is comparable to piling lumber within a yard, except that the roof of the shed, if it has wide projecting eaves, provides better protection from sunshine and wetting (Figure 39). Moderate size of piles, adequate spacing between piles, and arrangement of the air passageways in straight lines is as important in shed drying as on the yard.

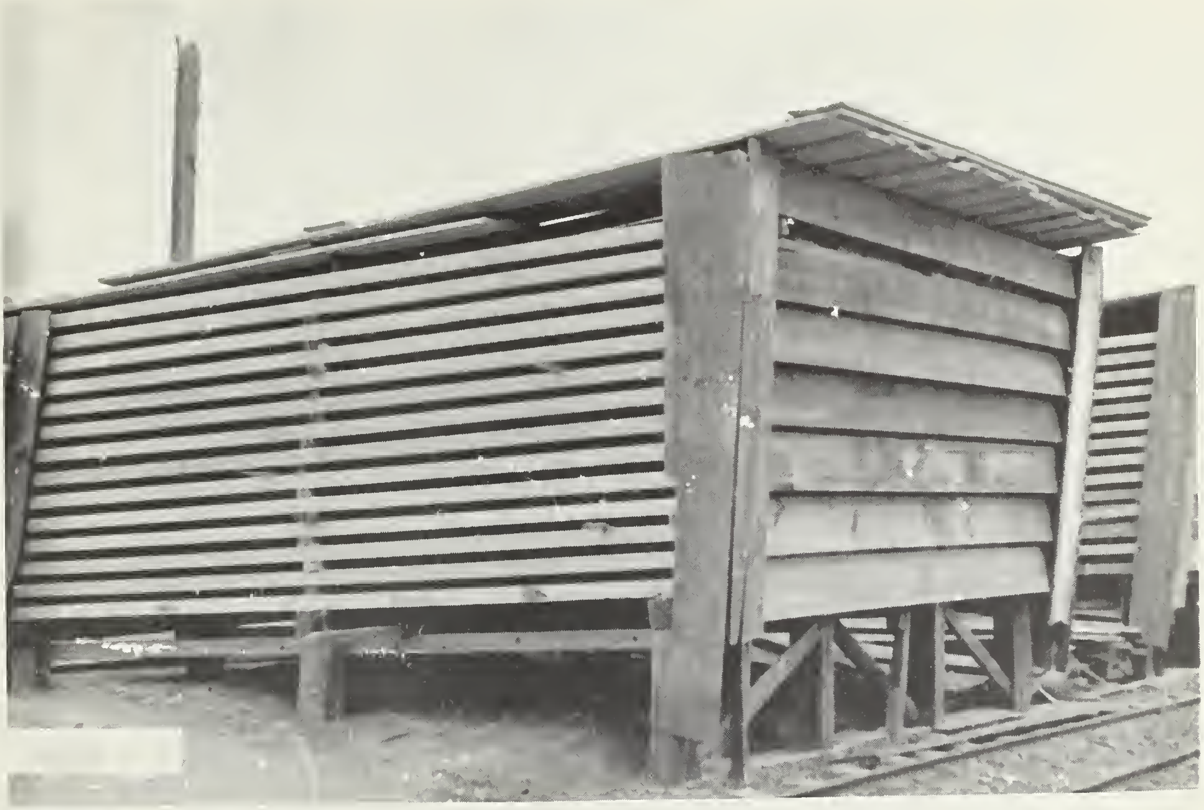


Figure 38.--Portable sun shields to protect the ends of the lumber from the sun.

Figure 39.--An air-drying shed of the pole-barn type.

A shed for air drying does not have to be open on both sides and both ends. In fact, some protection on the windward side is necessary in dry climates. If the shed is completely enclosed, provision should be made for ventilation. The sun may heat a closed shed so that the average temperature inside is above that outside. Lumber within such a shed may dry somewhat faster than lumber in a yard. The principal difficulty with such a system is that the hot air tends to remain near the roof. Some method of stirring up the air or circulating it so that the hot air can be brought to the lower levels is highly beneficial.

DRYING DEFECTS

Drying defects reduce the quality of the lumber and represent a loss to the producer or to the user. Air-drying defects may be caused by shrinkage or by fungal or chemical action. Shrinkage causes surface, end, and honeycomb checking, splitting, and warping. Action of fungi cause blue or sap stain, decay, and mold. Chemical reactions cause sticker stain or brown stain.

Defects Caused by Shrinkage

It is normal for wood to shrink during drying, but if it shrinks too rapidly or unevenly, defects can result. Defects are also caused by large variations in shrinkage in the different grain directions. Although the weather conditions are not subject to control, some control of the conditions within the lumber piles can be exercised by adjusting the pile spacing and the spaces within the pile. Narrower spaces between piles and less space within the piles will retard drying, and may reduce the magnitude of the drying defects associated with shrinkage. Other measures, such as those mentioned below, may also be beneficial.

Checks.--End checks originate on end grain surfaces of logs and lumber. They appear as radiating lines pointing toward the pith of the tree. They occur at the junction of the wood rays and the remainder of the wood cells, or within the wood rays. After having started, they become wider and extend radially and longitudinally. End checks in thick oak are shown in Figure 40. They may be controlled by end coatings.

Surface checks are similar failures in the wood, but they occur on tangential or flat-grain faces when drying conditions are too severe. They grow by becoming wider, longer, and deeper. They may consist of many short checks or a few long ones, as shown in Figure 41.

Honeycomb checks are internal openings. They may result from surface or end checks that have closed on the surfaces, or they may result from tensile failures entirely within the interior of the piece. Honeycomb checks cannot be detected until the piece is dressed or sawed (Figure 42), unless depressions or grooves appear on the surfaces.

Figure 40.--End checking and splitting in heavy oak.

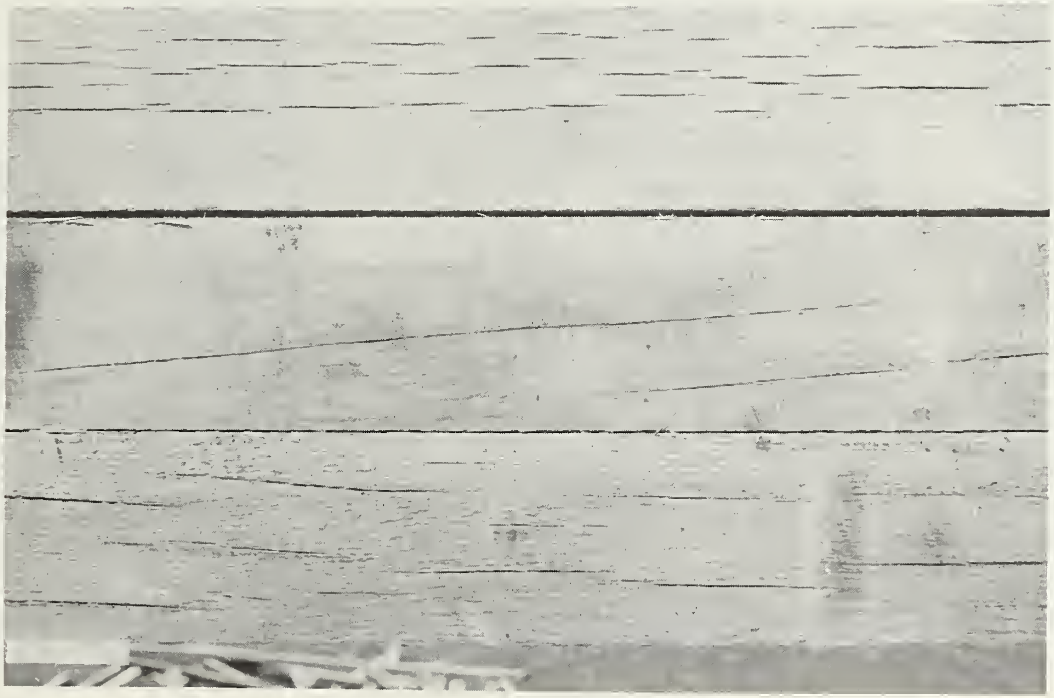


Figure 41.--Surface checks in oak boards.

Figure 42. --Honeycomb checks in oak that show up when the boards are crosscut, ripped, or planed.

Shrinkage also can cause failures or openings in planes at right angles to those of end, surface, and honeycomb checks. These failures occur either within the growth rings or at the junction of two rings. They resemble ring shakes, but ring shakes occur within a living tree. These other failures, which are sometimes called ring separations, are the result of drying.

Splits.--Splits resemble checks, but they generally start at one end of a board and extend along its length. In addition, splits often extend completely through the thickness of the board. Logs often contain longitudinal stresses that are retained by the lumber sawed from the logs. If such a board end checks and develops a slight split, this split often extends a considerable distance along the length of the board. The two portions of the board fan out or separate at the end. Some splits are shown in Figure 40.

Cracks.--Cracks resemble checks or splits, but their basic cause is the inherent difference between tangential and radial shrinkage. They occur where the pith of the tree is contained within a board or timber.

Shakes.--Shake is a ring separation that is present in the log and is not ordinarily considered a drying defect. However, shakes may become extended during drying and develop into splits or internal openings that resemble honeycomb checks.

Warp.--Warp is any deformation or change in shape (Figure 43). Warp can be divided into cup, bow, crook, twist, and distortion of the cross section. These terms are defined as follows:

Cup. A deviation flatwise from a straight line across the width of the board.

Bow. A deviation from flatness along the length of the board.

Crook. A deviation edgewise from a straight line from end to end of the board.

Twist. A deviation from flatness of a board so that the four corners of any face are no longer in the same plane.

Distortion of the cross section. A square becomes a diamond and a circle becomes an oval, because of differences between tangential and radial shrinkage.

Cup is common in flat-grained or plainsawed boards, and all such boards will cup if permitted to shrink and dry without restraint. In a cupped board, the face that was nearest the bark will be concave. Bow, crook, and twist may be caused by spiral or diagonal grain, localized distortions of grain, juvenile wood, or reaction wood. A board containing these forms of irregular grain or reaction wood is likely to warp because some portions of the board tend to shrink lengthwise, while others do not.

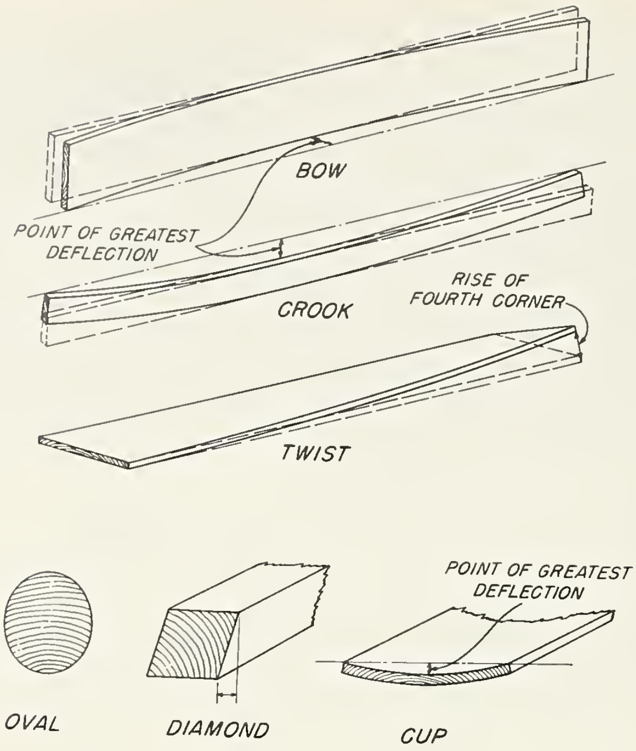


Figure 43. --Various kinds of warp.

Loosening of knots. --Unless knots are intergrown with the wood around them, they generally loosen during air drying. The loosening of knots is caused by a combination of the shrinkage of both the knot and the wood surrounding the knot. Intergrown knots, whose fibers are continuous with those of the trunk, do not loosen during air drying. They may, however, develop checks that appear as lines radiating from the pith of the knot.

Chemical Stain

Blackish or brownish streaks occurring across the faces of boards where they were in contact with the stickers, or dark streaks and patches in other portions of the board, may be chemical stain. This discoloration results from the concentration and oxidation of certain materials normally present in the sap. Retarded air drying encourages staining, particularly when outdoor temperatures are relatively high. The additional retardance caused by contact with the stickers results in sticker stain, the most common form of chemical stain.

Chemical stain can be reduced by encouraging rapid drying and by the use of narrow, dry stickers. Rapid air drying can be promoted by keeping the yard surface free from vegetation and debris, by providing high and open pile foundations, and by adequate spaces in the piles, between the piles, and between rows of piles. The piles themselves can be opened up by using thicker stickers or by increasing the amount of chimney or flue volume. End piling and end racking also diminish staining.

Defects Caused by Fungi

Blue stain, mold, and decay are caused by fungi. These minute organisms feed on the contents of the cells and also on the cell walls themselves. In addition to food, they require a certain amount of moisture and air. After a tree is felled and cut into logs, the log ends and other exposed portions are susceptible to attack by fungi. Freshly sawed lumber is also attacked. Storage of the logs or green lumber under water or in a sprinkled pile prevents the growth of these organisms. Once the seasoning is started, however, the material is subject to fungus damage unless chemically treated. Even after a good dipping treatment it is necessary to protect the lumber from rain and dry it rapidly to prevent damage in very humid climates.

Stain. --The sap stain or blue stain fungi grow in the sapwood of both softwoods and hardwoods. Infection generally starts on the surfaces and the organisms sometimes penetrate the entire board. The fungus is propagated by spores that are airborne and are practically always present, except in the winter in cold climates. These spores come to rest on the surfaces of freshly sawed lumber and infect it. If the conditions of air, moisture and temperature are favorable, they develop quickly into fungi. Sap stain fungi develop at temperatures of 40° to 100°F., but the optimum temperatures are between 65° and 85°F. Spores, although generally carried by the wind, may be carried by bark- and wood-boring insects. Although blue stain does not materially affect the strength properties of wood, it does detract from the appearance. In addition, blue stain may be followed by decay which seriously affects the strength of the wood.

Blue stain can be controlled by the use of antistain chemicals. Where chemicals are not available, the next best method of control is to pile the lumber in such a way as to encourage rapid drying, such as by end racking, end piling, or flat piling with narrow, dry stickers.

Mold. --Mold is a fungus that is propagated by airborne spores, as is the blue stain fungus. Mold develops during warm, moist weather. Mold grows on the surfaces of wood and also penetrates to the interior. Since the hyphae or threads are colorless, they do not stain the wood. The discoloration of the surfaces of the wood is caused by the fruiting bodies. Under exceptional conditions, mold may develop to a point where it restricts circulation of air in certain portions of a pile and thereby retards drying. The measures used to reduce or control sap stain or blue stain apply also to mold.

Decay. --Decay or rot is caused by fungi that not only discolor wood but actually destroy it. Decay, blue stain, and mold all thrive under similar conditions of moisture content, air, and temperature. Decay requires somewhat longer to develop than stain or mold. Freshly sawed lumber may be infected by spores that are airborne or by coming in contact with decayed timbers of pile foundations or stickers.

Decay is frequently present in the living tree, and the boards sawed from such material will contain the organism. Some of these decay fungi may continue to develop as the wood dries. The best way to combat decay is to dip the lumber in solutions of toxic chemicals or to dry the lumber to a moisture content of 20 percent or less as rapidly as possible. Below this moisture value none of the organisms will grow, but they may become active again if the wood is wetted.

Defects Caused by Insects

Wood is attacked by insects, particularly when it is at a high moisture content, but it may be attacked at any stage of dryness. Some insects attack sapwood and some heartwood, and some attack all parts of the tree, including the bark. The powder-post beetle attacks the dry sapwood of such species as hickory, ash, and oak. Protection from insects may be accomplished by dipping the green lumber in a solution that contains chemicals toxic to fungi as well as insects. Insects also can be killed by subjecting the lumber to a temperature of 140°F. or higher in a dry kiln.

END COATINGS

Moisture-resistant coatings are sometimes applied to the end-grain surfaces of wood items to retard drying. By retarding drying they minimize or prevent the formation of end checks. Occasionally moisture-resistant coatings are applied to flat-grain faces of some items. To be effective, the coating should be applied to the fresh green wood before any checking has started. To coat surfaces that have already checked is of little value.

There are many types of end coatings produced and sold by commercial organizations (Appendix C). End coatings may be divided into two types, those that are applied cold and those that are applied hot. Cold coatings may be applied by a swab, brush, or spray. Hot coatings may be applied by dipping, or by a simple machine that resembles a glue spreader. Many cold coatings are heavily filled varnishes, while hot coatings are asphalt, coal tar, or paraffin. Irrespective of the type of end coating or the method of application, it is highly important to attain a thick covering. Two or three coats are sometimes necessary, particularly where a thinner has been used and the coating applied by spraying.

The cost of applying an end coating generally amounts to 50 cents to $3.00 per thousand board feet in the United States. Whether or not it is profitable to use end coatings must be decided by comparing the cost of the coating and the labor to apply it to the value of the lumber that is saved by a reduction in end checking and end splitting. End coatings are more commonly applied to thick, high-quality lumber and timbers than to thin, low-quality boards.

DRYING PERIODS

The time required to air dry lumber to a specific moisture content, 20 percent for example, varies tremendously. It varies with the geographic location, the season, the species, and thickness of the lumber, the characteristics of the yard and its layout, and the features of the lumber piles.

Air-drying time may vary from 1 week to several years. Information concerning drying periods pertaining to specific lumber items air dried within a particular yard can be obtained only by conducting studies. In various areas of the United States air drying 1-inch lumber to 20 percent moisture content takes 40 to 300 days for hardwoods and 16 to 200 days for softwoods, except that baldcypress takes up to 300 days and sinker redwood up to 365 days.

PREDRYING

The object of predrying or accelerated air drying is to dry the lumber to a moisture content of about 20 to 30 percent more rapidly and economically than by air drying or shed drying. The moisture above 30 percent is free water. In softwoods and easy-to-dry hardwoods such water moves to the surface rapidly, and the major factor in drying it is evaporation. Artificial circulation of air over the lumber tends to speed up evaporation.

In its simplest form, predrying is air drying with horizontal air circulation through the piles, produced by mechanical means. A moderate investment in fans and motors and a source of power are needed. Also needed are pile coverings or low-cost buildings, and interior baffles that force the air to go through the lumber. The fans can be used during the hottest or driest parts of the day to force extra quantities of air at high velocity over the lumber. During cool and damp days or during the night, the fans should be shut off to save power and to keep the wood from regaining moisture.

Another form of predrying employs a small amount of heat, particularly during cool and damp weather. When artificial heat is used, a building designed to recirculate the heated air is required to make the process economical.

In return for the costs of equipment and power, the drying rate may be about 2 to 2-1/2 times as fast as air drying. The cost of air drying and predrying are about the same. The advantage of predrying is to be able to produce semi-dry lumber under any weather conditions and provide a better quality product. Shortening the drying time and protecting the lumber from rain and sun combine to produce the better quality. Ordinarily the better quality will mean a higher selling price for the lumber.

Predrying has not been developed to a stage where best types of equipment and best methods can be described. The following information has been included here to outline the general factors involved from which one could design and build proper equipment if a predryer appears necessary.

UNHEATED SINGLE-PASS PREDRYER

In a single-pass predryer, the outdoor air is either pushed or pulled through the lumber piles by means of power-driven fans or blowers. The piles may be located in the yard or within an inexpensive building (Figure 44). After the air has passed through the lumber piles, it is exhausted to the outdoors. The lumber piles are placed on both sides of a rectangular space. Walls at the ends of this space contain the fans or blowers. The top of the space and the piles themselves are roofed over. All other openings are blocked off so that a plenum chamber is formed, and the air is compelled to pass through the lumber piles. The fans or blowers may be operated so as to either push or pull the air within the plenum chamber. A more uniform distribution of circulating air is generally obtained by pulling the air from the plenum chamber.

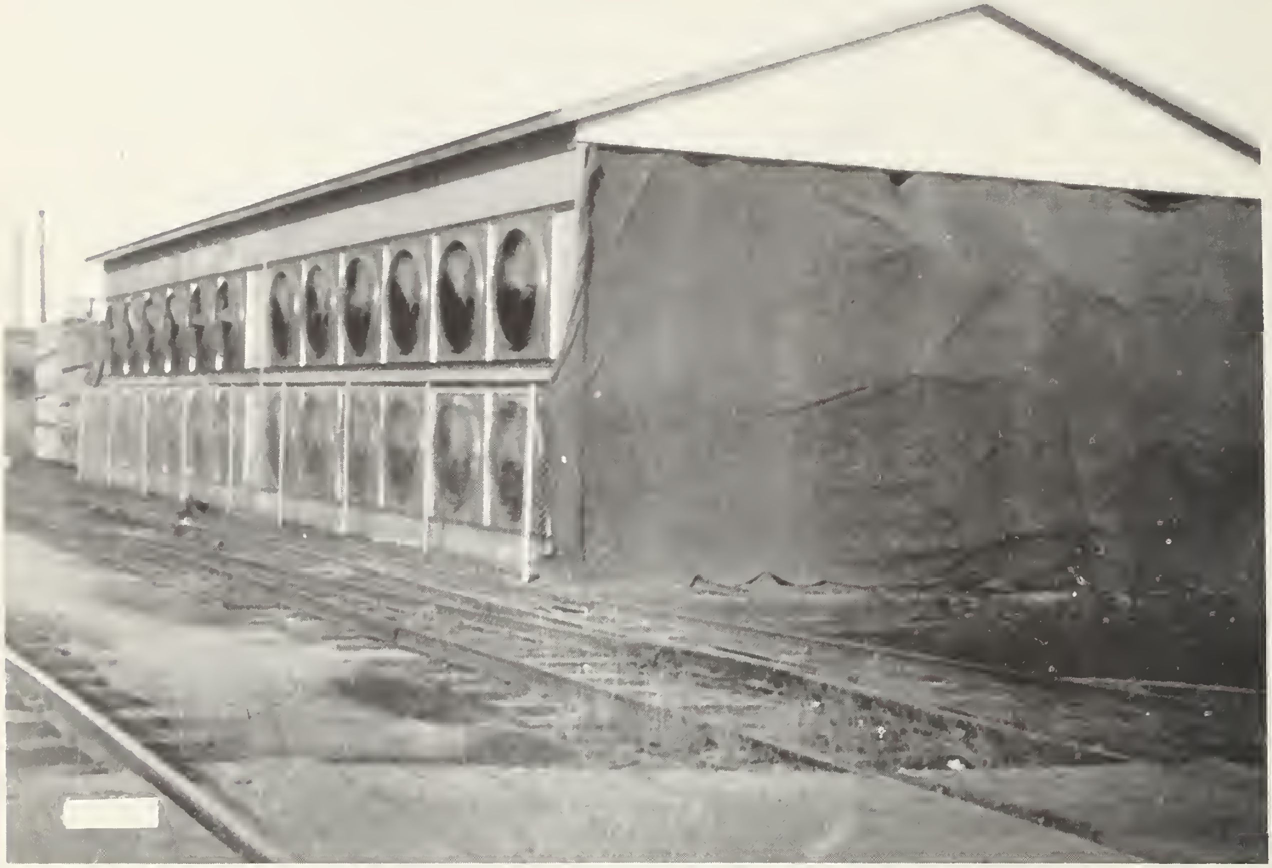


Figure 44.--Unheated single-pass predryer.

The roof, end walls, and baffles should be reasonably air- and watertight, but do not need to have a high insulating value. They can be made of any available material. Since lumber is always available at a sawmill, low-quality boards can be used. If boards are laid across the opening and across the top of the pile, they should be in an overlapped double layer and sloped slightly to prevent entry of rain. Any space between the top of the piles and the roof should be baffled to prevent short-circuiting of air.

The fans or blowers may be driven by any source of power that is available. They are commonly driven by electric motors, but may be driven by internal combustion engines, steam engines, water wheels, or windmills. A brisk to rapid air movement through the layers of lumber is required to make the process worthwhile.

HEATED RECIRCULATING PREDRYER

This type of predryer requires a complete enclosure. The fans or blowers and lumber piles are inside of a structure. The major part of the air within the building is recirculated. A moderate source of heat is required. If the walls and the roof of the structure are reasonably tight, then intake and exhaust vents are necessary. In order that the circulating air will pass from the fans or blowers through the lumber piles and return to the fans or blowers, a system of ducts or plenum chambers is needed. In addition, baffles should be provided to prevent short-circuiting of the air.

Figure 45 shows a combination predryer. When the side panels are open as shown, it operates as a single-pass system. When they are closed it becomes a recirculating predryer.

Figure 45.--Combination single-pass and heated recirculating predryer.

A heated recirculating predryer differs from a regular dry kiln in the type of construction and the details of operation. The walls and roofs should be reasonably air tight, but do not need to have high insulating values. They can be of lower quality than the walls and roofs of dry kilns, since they do not need to be resistant to high temperatures and high relative humidities.

The heating system can be limited to a few runs of pipe heated by exhaust steam or hot water, or a heat exchanger composed of metal or ceramic material that contains a direct fire. While a dry kiln is generally supplied with steam spray lines or water sprays to maintain and control relative humidity, these are not provided in a predryer. Relative humidity is controlled solely by the vents. Expensive automatic instruments are not necessary. A manually operated means to reverse the direction of the fans at given intervals, thus reversing the direction of circulation, would be desirable.

One source of heat that is available everywhere is the sun. Any object upon which the sun shines is heated, but usually most of this heat is dissipated, either by radiation or by convection. The amount of heat absorbed depends upon the characteristics of the material, among which an important one is the color. The amount of heat dissipated depends upon the certain surface characteristics and the exposure of the object to cooler circulating air. Basically, a dark-colored object with a dull surface absorbs more solar heat than a light-colored object with a shiny surface. Some of the heat absorbed will be lost by radiation, however. Radiation losses can be reduced by use of an outer layer, or membrane, of glass or some transparent plastic between the object and the sun. This transparent layer permits the penetration of the sun's rays, but greatly reduces the heat loss through radiation and convection.

A solar-heated predryer does not require any heating coils or heat exchangers. However, since solar heat is absorbed principally by the roof and the upper walls exposed to sunshine, it is necessary to move the heated air in the upper part of the structure to lower levels by fans or blowers. Otherwise, the hot air will tend to remain in the upper part of the structure.

A solar-heated predryer can be constructed of a wood framework covered with sheet metal. The sheet metal should preferably be painted a dull black on the outer surface. The air within the predryer should be moved across the heated surfaces of the roof and wall and be forced to move through the lumber piles before returning to the fans or blowers. If the predryer did not contain any lumber piles, the relative humidity within the structure would be appreciably lower than that outdoors. When the predryer is loaded with green lumber, moisture given off by the lumber will increase the relative humidity. To reduce this relative humidity it is necessary to introduce fresh air from the outdoors and exhaust moist air through vents. Whatever leakage there is in the walls or roof of the structure will reduce the amount of venting required. During the early part of a drying process, it may be desirable to keep the vents partly or fully closed in order to maintain a high relative humidity to prevent checking. Later it may be desirable to operate with the vents wide open.

An outer layer of glass or transparent plastic material will increase the temperature within the predryer. The drying rate of the lumber within such a predryer will be higher than that within a predryer whose walls and roof consist of a single sheet of metal. All other aspects of the operation will remain the same.

Not only should the lumber dry more rapidly within a predryer than on a yard, but the roof and the walls of the predryer will protect the lumber from the weather. Such protection will be more efficient than that provided by a roof on a yard pile. This more efficient protection from the weather will result in less deterioration during drying than is ordinarily experienced during yard drying.

KILN DRYING

The principal difference between kiln drying and air drying is that heat is supplied in the kiln to accelerate the drying and to make it possible to dry the wood to low moisture content values. The heat raises the temperature above the temperature outdoors. If this temperature difference is great, then an extremely low relative humidity results unless some additional moisture is supplied to the air within the kiln. Kiln drying also differs from predrying in that kiln drying is a controlled process in which moisture is often supplied to the air within the kiln to maintain specific relative humidities according to a definite kiln schedule. Also, relatively high temperatures and sometimes high relative humidities are used near the end of drying to finish off the process. A dry kiln requires a better and more costly structure to resist the action of high temperatures, high relative humidities, volatile acids, and other materials from the wood, and to reduce the loss of heat.

Kiln drying is the best drying method when the lumber's end use requires a lower moisture content than that which can be obtained by air drying. The low moisture content requirements arise from the use of the wood in dwellings or other buildings that are heated part of the year. Where buildings are not heated, thoroughly air-dried lumber can be used for furniture and other items. Where a dry kiln is not available, small quantities of lumber can be dried to a low moisture content in a heated room. Drying time in such a room is considerably longer than kiln drying time and drying stresses cannot be relieved.

Kiln drying at relatively high temperatures has other advantages over air drying, predrying, or room drying. The high temperatures kill stain and decay fungi and insects. Where the wood contains gums or resins, the high temperatures may drive off the more volatile substances and make the residue more stable and less subject to "bleeding."

There are several types of dry kilns, ranging from the simpler types to the most modern, automatically controlled kilns. It is impractical to describe them all here. In order to bring out the most important kiln-drying principles and give practical information for use where extensive supplies of modern equipment are not yet available, a few types are described. For this purpose, drying in a heated room is included. Also described are a small hot-air kiln, small natural circulation kiln, and a forced-circulation furnace kiln. Some information is given on modern, forced-circulation, steam-heated, internal fan kilns. More information on types of modern kilns and greater details on kiln operation are given in the "Dry Kiln Operator's Manual" (Appendix A).

Kilns are generally built of locally available materials or those that can be purchased cheaply. Seasoned wood can be used satisfactorily. Locally made bricks should also be usable. Concrete, concrete blocks, brick, terra cotta tile, asbestos-cement board, and sheet metal also can be used. Some of the important features of design and material are covered in descriptions of the few kilns described in this section.

HEATED ROOM DRYING

In heated room drying, a small amount of heat is used to lower the relative humidity. This also lowers the equilibrium moisture content to which the wood will come if left in the room a long time. This method is suitable only for wood that has been air dried first. Green lumber may check and split badly by this method. This method does not dry lumber rapidly, but it is suitable for small amounts of lumber. Before the drying is started, the lumber should be cut down as close as possible to the final size it will have in the product. Allowance must be made for some shrinkage, some warping during drying, and a small amount to be removed during planing and machining. If it is necessary to cut some long pieces before heated room drying is started, the freshly cut ends should be end coated to prevent end checks, splits, and possible honeycomb.

For reasonably fast heated room drying, the wood should be exposed to an equilibrium moisture content condition about 2 percent below the moisture content of use. The wood is left in the room just long enough to bring it to the desired average moisture content. Then the wood is taken out and stored in a solid pile until it is used. The storage area should have the same equilibrium moisture content as the area in which the wood will be used.

The amount that the temperature must be raised above the average outdoor temperature depends upon the average outdoor relative humidity. Typical values are given in Table 8. Do not attempt to use greater amounts of heating with this method.

Table 8.--Amount to raise temperature for various ECM values in heated room drying

EMC value desired	Degrees above average outdoor temperature at--		
	65 percent relative humidity	75 percent relative humidity	85 percent relative humidity
Percent	°F.	°F.	°F.
7	18	22	-------------
8	12	18	22
9	8	11	18
10	5	9	14
11	2	6	11
12	-------------	4	9
13	-------------	2	6

Any ordinary room or shed can be used and any ordinary means of heating the room should be satisfactory. A slight amount of air circulation would be desirable to achieve temperature uniformity, but it is not necessary. If the material is relatively small-sized, it can be piled in small, stickered piles on a strong floor. It also could be sticker piled on carts that can be pushed in and out of the room. Long lumber should be box piled on strong, raised supports as shown in Figure 46.

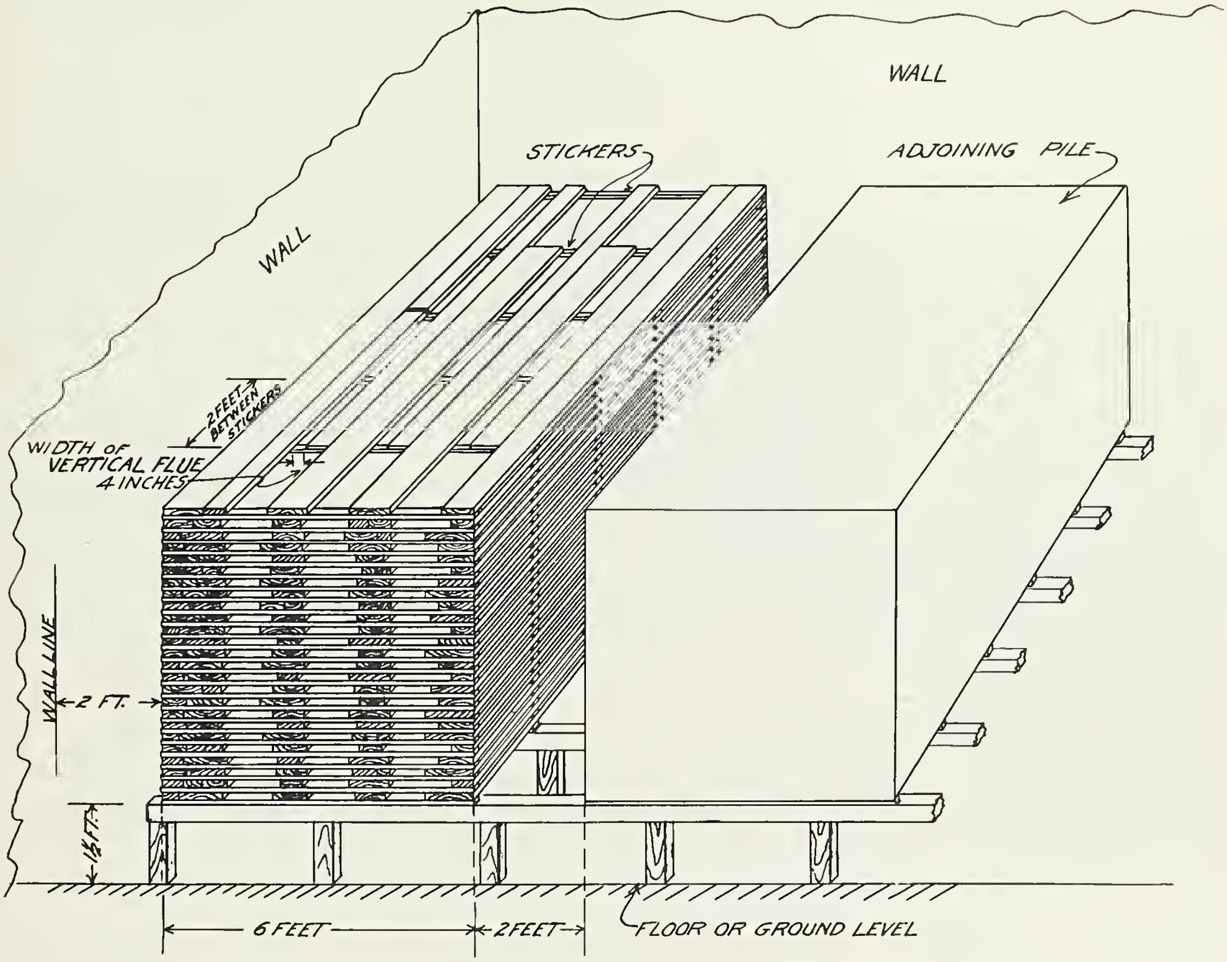


Figure 46. --Lumber piled for drying in a heated room.

The lumber should be marked or records kept as to when it entered the room and when to expect to remove it. Any amount of air-dry lumber can be put in or dried lumber removed without upsetting conditions. The doors should be kept closed as much as possible so that the average temperature can be kept close to the desired elevation above average outdoor temperature. Variations of the average outdoor temperature from night to day and small variations from day to day do not affect the process.

SMALL HOT-AIR KILN

Green softwoods, some green easy-drying hardwoods, and any hardwoods that have been air dried can be kiln dried in a homemade hot-air kiln (Figure 47). The natural circulation type of operation is used. In the central area of the kiln, a firebox and smokepipe heats the air and causes it to rise. The hot air is carried over the top of the two piles of lumber and goes down through the pile to a space underneath. Then it passes back to the central area and rises again. As the air circulates, moisture escapes to the outside air through cracks in the structure, particularly at the top of the front panels.

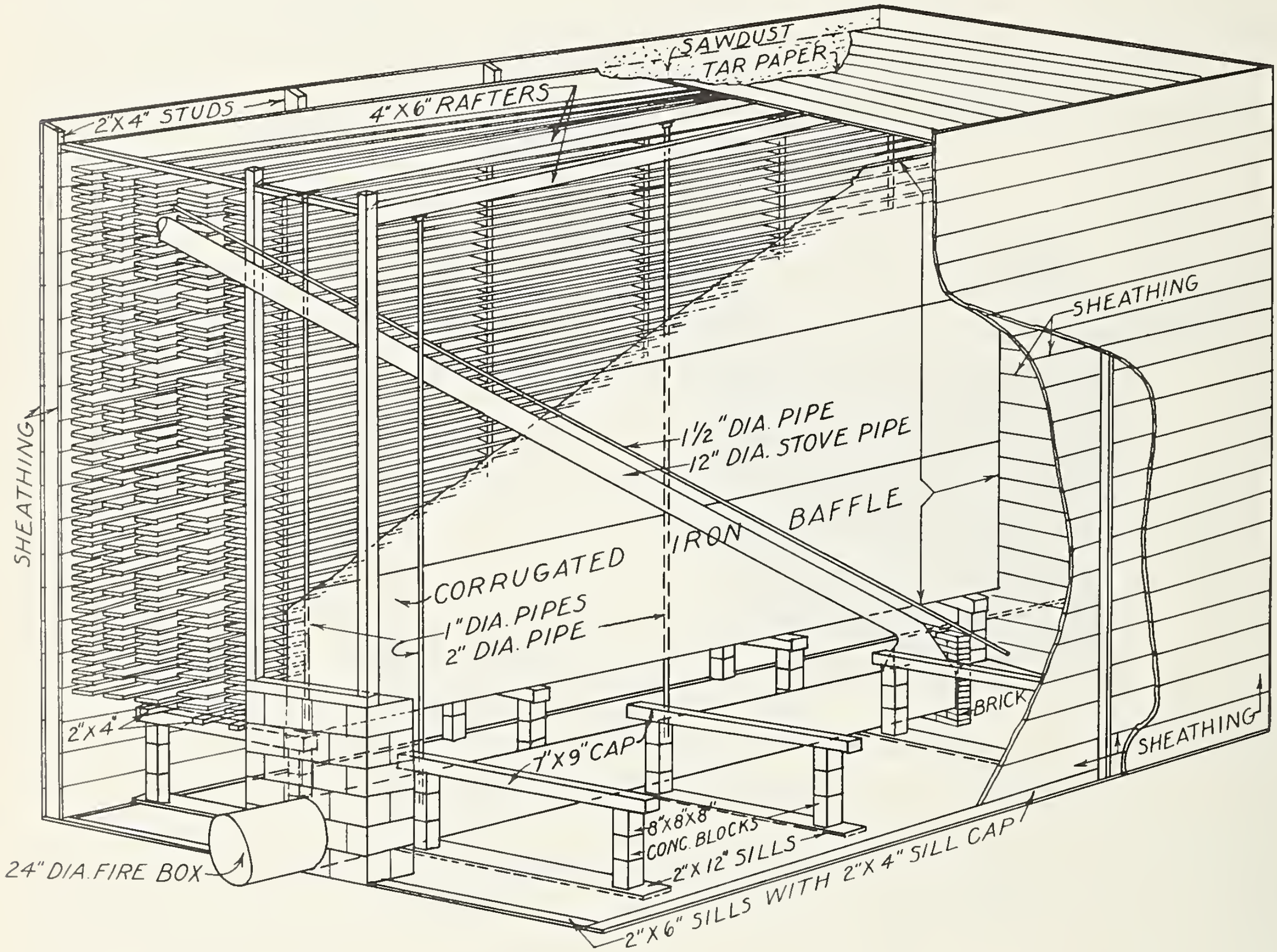


Figure 47.--General design of small hot-air kiln.

Slabs and edgings from the sawmill are burned in the firebox. The drying conditions are not closely controlled, but a small amout of experience will determine how big a fire to make and how long to dry each species of lumber. Results will not be as good as those from a fully controlled automatic kiln, but the method will dry lumber faster than a heated room, and the lumber will be suitable for building and many other purposes. One-inch lumber can be dried in 4 or 5 days.

The capacity of the kiln is about 7,000 board feet. If the sawmill cuts about 7,000 board feet per day and the owner wishes to kiln dry all of the cut, five or six such kilns would be required.

Building the Kiln

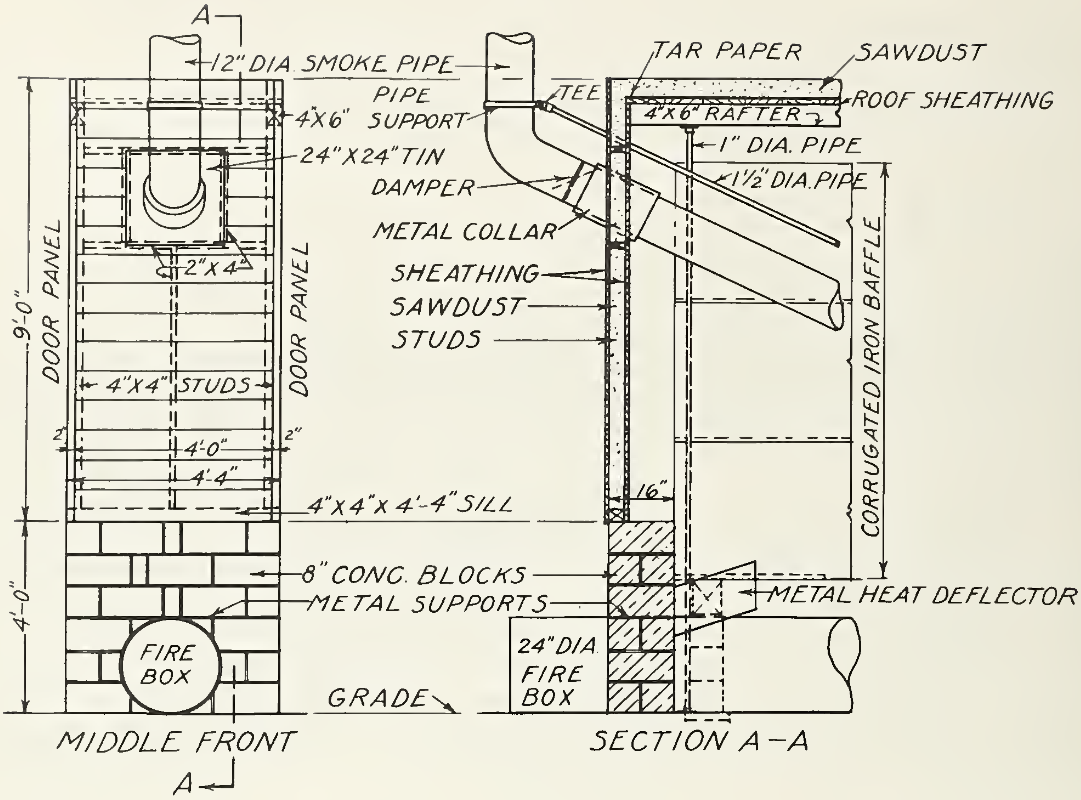
Location.--A site for the kiln should be selected about 60 feet or more away from the closest lumber pile, building, or other combustible material.

Firebox.--The firebox is laid first. It is made of a section or iron or sheet metal pipe about 2 feet in diameter and 2 feet longer than the lumber to be dried. It may be a piece of factory smokestack, heavy road culvert, or steel drums with ends knocked out and welded together. This should be laid in a shallow trench. The rear end should be closed tightly with brick or a heavy metal plate. A round hole for a 12-inch smokestack is cut in the upper side of the firebox near the closed end. A sheet iron plate should be made to place over the front end of the firebox to serve as a fire door and held control the draft.

Lumber pile supports.--The foundations to hold one stack of lumber on each side of the firebox are built next. Each foundation consists of four supports. Each support has a 6- or 7-foot sill sunk slightly below ground level, two uprights of concrete blocks or square stones, and a crossbeam or cap. The tops of the caps all should be on the same level to support the lumber evenly. Upright timbers or posts can be used in place of the concrete blocks or stones, but wood next to the firebox should be protected from the heat. Supports built by piling up timbers should not be used. They stop proper air movement.

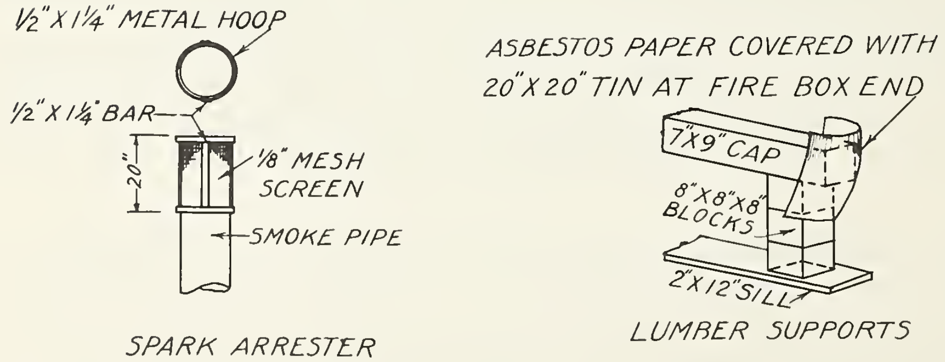
Kiln structure.--A wood-frame building is placed around the firebox and pile supports. Its design and method of construction are shown in Figure 47. The frame is made of 2- by 4-inch air-dried rough lumber. The 2- by 6-inch sills should be of heartwood that is resistant to decay and insects. The sides and back are built first, with the back about 2 feet away from the closed end of the firebox. The inside wall is about 6 inches away from the ends of the pile supports. The open end of the firebox should extend about 2 feet out from the front end of the side walls. Both inside and outside of the walls are sheathed with 1-inch boards. The inside sheathing should be very well air-dried lumber nailed tightly edge to edge. The walls are filled with sawdust.

The front middle-section frame should rest upon a brick, stone, or concrete block section built around the firebox (Figure 48). Another way is to use a small stone enclosure around the firebox and run the front frame members down to front sills. A top frame member can be run across the front. Bracing should be used here. Each side of the front up about 2-1/2 feet from the ground and about 2 feet down from the top can be framed, sheathed, and filled with sawdust the same as the side walls (Figure 49). Detachable door panels made of two layers of boards at right angles to each other, with tar paper between, cover the front openings. The middle section wall may be double-sheathed frame construction (Figure 48) or double-layer board type with inspection door or window (Figure 49).



MIDDLE FRONT

SECTION A-A



SPARK ARRESTER

LUMBER SUPPORTS

Figure 48.--Details of small hot-air kiln.

Figure 49. --Hot-air kiln being loaded.

The roof consists of panels about 3 feet wide made of a single layer of air-dried boards nailed to two or three cross pieces. The board panels are long enough to rest on top of the inside wall sheathing but do not reach to the outside sheating. The side wall frame members and the outside layer of sheathing extend 6 inches higher than the inside sheathing (Figure 47). The panels also will rest on the two central rafters which are braced at the center by 2-inch iron pipe. Enough panels are made to cover the entire top. The back panel is nailed down, but the others are loose. After being fitted for size, they are temporarily placed on the rear panel so that the top layers of lumber can be piled up close to the roof.

Enough sawdust to fill the side and end walls and to cover the roof panels 4 inches deep should be laid out and dried.

Smokepipe and fire safeguards. --A smokepipe is connected to the rear of the firebox after the kiln is built. An angled elbow is used to bring the smokepipe forward and up. It passes out of the middle front panel about 2 feet below the roof. Heavy wires or straps should support the smokepipe below an iron pipe. The top portion of the central front panel, or at least a 2- by 2-foot portion of where the smokepipe passes through, should be of sheet metal or corrugated iron. A 16-inch metal collar should be centered right around the smokepipe where it passes through the metal panel, allowing a 2-inch space between smokepipe and collar. A damper can be placed in the smokestack just above the collar, or can be fitted to the end (Figure 49). The better arrangement is to use the inside damper and another angled elbow and extra smokepipe to carry the smoke at least 6 feet above the kiln roof. A spark arrester (Figure 48) should be used.

Unless safeguards are taken, this kiln may catch fire. The sills should be covered with dirt or hard-packed clay, smooth stone, or brick. The caps of the pile supports should not be closer than 1 foot to the firebox, and the nearest ends should be insulated with asbestos paper protected by tin shields.

Both as a fireguard and a means of forcing air circulation up, corrugated iron sheets should be attached to the 1-inch and 2-inch rafter supports at the side of the pile nearest the firebox. These corrugated iron sheets or baffles start at the top of the load supports and rise to the top of the lumber pile, about 1 to 1-1/2 feet below the roof. They should extend from front to back of the kiln. An 8-foot sheet of corrugated iron is erected between the back of the firebox and the back wall to protect the wall from fire. The front wall around the firebox should be made of brick, stone, or concrete blocks laid in a hard-setting mortar. The joint between the firebox and the wall should not be tight.

Even when all safety measures have been take in constructing the kiln, fire can result if too hot a fire occurs. This is why the kiln should be located a safe distance from lumber piles and other buildings.

Loading and Roofing

About 5,000 heartwood stickers, 1 by 1-1/2 inches by 6-1/2 feet, should be sawed out and air dried. In loading the kiln, six green 2- by 4-inch pieces are placed at uniform spacing on top of each pile foundation. Seven stickers are then placed across the 2 by 4's, one over each support, the others midway between supports. Then the lumber is box piled, with full length boards on the outside and other lengths, as they come from the sawmill, in between. Only one thickness of boards should be piled in the kiln at a time. If this separation of sizes is not possible, care should be taken to get boards of uniform thickness in a course. This helps to support all parts of the pile and prevents warping. Flue spaces about 4 inches wide should then be left in the pile over each of the spaces between the bottom 2 by 4's. These flue spaces should be straight up and down. The stickers also should be alined straight up above the bottom stickers. Short pieces of board should be used as blocking when there are not enough long boards to keep good support all the way up in a pile.

The pile is built up to within 1 foot of the bottom of the roof panels. Boards for the top of the pile may be passed down through the open roof.

When the kiln is loaded, the roof panels are put in place. Strips of tar paper are laid, overlapping their edges, from front to back of the roof. About 4 inches of dry sawdust is placed on top of the tar paper. Extra sawdust should be put down in the walls and at the top of the walls where they join the roof. The front panels are put on the kiln, and it is ready to start.

Operation and Unloading

A fire is started in the firebox and kept going day and night until the lumber is dry. To start drying green lumber, a very hot fire should be used. The progress of drying can be told by feeling the air that escapes from cracks at the joints of front and side walls. If the fingers feel moist after about a minute in this air, the lumber is still fairly wet and a hot fire should be kept up. Green slabs and edgings generally should be used as fuel, to avoid so hot a fire that it will burn the lumber. As the kiln load dries, the sawdust joint at roof and walls may open. If it does, more sawdust should be added.

When the lumber begins to get dry, the escaping air will feel drier and hotter. Then a smaller fire should be used. A little experience will show a kiln operator how hot a fire to carry each day of operation, and when to stop the drying of each species and size. Two-inch lumber will take more than twice as long as 1-inch lumber.

As soon as the lumber is dry, the fire is stopped. The sawdust on the roof is swept to the rear panel. The tar paper is rolled back to the sawdust, and the loose roof panels are taken up and piled on the sawdust. The lumber is taken out and piled in solid piles for storage or on wagons or trucks for shipment.

A suggested bill of materials for this kiln is given in Appendix F.

SMALL NATURAL CIRCULATION KILN

In a natural circulation kiln, the air is heated by steam coils or other heat exchangers. It rises in the open spaces, then moves downward through the lumber pile because the air is cooled as the moisture in the lumber evaporates. With proper design this type of kiln will dry a greater variety of lumber with greater speed and better moisture uniformity than the hot-air kiln can. It does not give as good results as the modern forced circulation kiln; the rate of air circulation is not very fast and the degree of control is not very good.

Natural circulation kilns are more substantially built and will operate properly much longer than the small hot-air kiln. With steam for both heat and humidity, they can be kept under closer control. Natural circulation kilns could very well fit into the early stages of a wood industry in any country.

Kiln Building

A small natural circulation kiln is shown in Figure 50. A permanent kiln capable of proper operation needs good foundations, walls, floor, roof, vents, and interior kiln coating, as well as tracks and trucks or load supports and a good heating system. A dry kiln is subject to extremes of temperature as well as very high relative humidities; so greater care and attention to details are necessary when building a kiln than when building an ordinary structure. Dimensions of such a kiln are not critical, but at least a 2-foot space should be allowed between each wall and the load, and the ceiling should be about 2 feet above the load. If the kiln is two tracks wide, a 2-foot space should be left between loads. There should also be at least 4 feet between the kiln floor and the lumber.

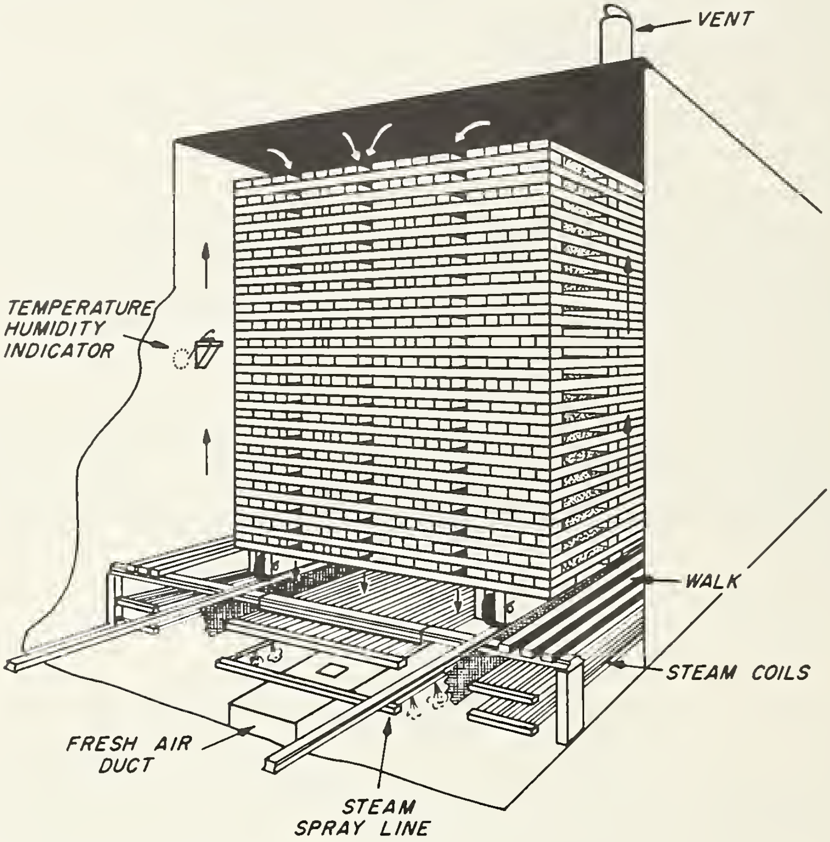


Figure 50. --A small natural circulation kiln.

Foundations. --Kilns must be built on firm foundations because settlement causes structural misalinement and cracks in the walls and roof. Tracks may be thrown out of line. Kiln foundations are usually made of concrete. Where concrete is not available, stones or decay-resistant or preservative-treated timbers may be used. The width of bearing area is determined by the character of the soil and by the loads to be carried. Foundations are usually about 10 inches thick where wood walls are used above grade. If the kiln walls are to be of masonry, the foundation should be the same thickness as the walls; concrete foundations should be waterproofed with an asphalt coating if they are likely to be in contact with ground water. A kiln such as this, where heating coils are placed below the load, should not be built in an area with a high water table. If the soil is difficult to excavate, the kiln can be built at ground level and the lumber tracks placed at a higher level.

One method for supporting foundations in soft ground is to use poured concrete or stone footings about 2 feet wide, but only about 8 inches deep, under the entire foundation. Footings also should be used for posts that will support the loads of lumber, the heating coils, or the roof. In cold climates the exterior foundations should go down slightly below frostline.

Walls.--The walls must be strong enough to support the roof and any other equipment. They also should be resistant to heat and vapor transmission. If made of brick, they should use the heavy, hard-burned type rather than soft brick. The brick should be laid in tempered cement mortar that will set up hard and dense. The walls should be 13 inches thick and strengthened with pilasters not more than 20 feet apart. If terra cotta tile is used, it should be of the dense, load-bearing, hard-burned type laid in tempered cement mortar. An outer facing of brick or stucco is sometimes applied to tile walls. Tile walls should be 12 inches thick and reinforced with pilasters not more than 20 feet apart. Other materials such as wood, concrete blocks, and poured concrete can be used for walls. These are not discussed here but are discussed under descriptions of other types of kilns. The inside surface of a kiln wall should be as smooth and tight as possible.

Floor.--The best material for a kiln floor is concrete. Brick could be used, or a layer of clay that will harden. The natural soil or gravel can also be used, but it is not as good. Use of cinders or porous volcanic rock beneath the floor would help conserve heat.

Roof.--A good kiln roof must be structurally sound, weatherproof, durable, and resistant to heat loss.

A crib or laminated wood construction can be used. Planks 2 by 8 inches are laid on edge, face to face, to span the width of the kiln. They are firmly nailed together. Large bolts can be set in the walls at intervals to bolt down such a roof. When a roof of this kind is used, protection should be provided by a pitched roof or cover to shed rain. The space between the cover and the kiln roof must be well ventilated. A crib roof of this type and thickness has a very good insulating value.

If the kiln has more than one track and is too wide for a single length of roof material, the center should be supported by a strong beam resting on posts.

Doors.--A kiln door should be strong but light enough to handle easily. It should be resistant to corrosive action and have good insulating properties. It also should stay straight and fit tightly. On a small kiln hinged double doors may be used. At least three, or better four, strong hinges should be firmly attached to the kiln walls on each side. The doors should be braced to prevent sagging and be at least double thickness of dry lumber with a layer of tar paper in between. Gaskets made of old fire hose or similar material should be placed on the door stop so as to insure a tight closure. The latch for the door should open from the inside of the kiln as well as from the outside so that no one would be accidentally locked inside.

Vents. --Most of the heated air in a dry kiln should be recirculated many times through the lumber, but some vents are needed to let out a small amount of moist air and take in a small amount of dry air. The outlet vents in a natural circulation kiln may be in the roof or may go through the walls into chimneys outside. The vents should be uniformly spaced along the length of the kiln. Sliding dampers control the amount of venting through wall vents, and hinged vent caps control roof vents. The amount of fresh air entering the kiln is controlled by a hinged door on the end of the fresh-air duct. This duct runs the full length of the kiln at the bottom. Openings uniformly spaced along the length let the fresh air into the kiln.

Kiln coating. -- Most building materials are porous and allow moisture vapor to pass through them. This vapor represents a loss of steam and lowers the insulating value of the material. It also causes damage to the walls and roof. Therefore, all joints are sealed tightly. Then a paint that possesses good resistance to vapor, such as an asphaltic or pitch paint or a regular kiln coating, should be applied to the entire inner face of the kiln walls and ceiling. Vapor leakage is also important in the walls between kilns, since it may interfere with relative humidity control in one of the kilns. The kiln coating should be renewed when needed, or at least every 2 years.

Load and Heating Coil Supports

As shown in Figure 50, it is convenient to have tracks leading into the kiln and support the load on kiln trucks. Since green lumber is very heavy, the track supports must be very strong. In a natural circulation kiln, the tracks must be elevated so that there is a 4-foot space between the floor and the bottom of the lumber. The heating coils and steam spray line should be suspended below the track supports, about 2 feet from the lumber. The tracks are supported on heavy railroad rail or I-beams. These are supported by strong posts that rest upon flat footings. Each end of the crossbeams could also be set into the wall; otherwise the whole structure should be braced. Walkways along the side of the kiln are laid on the track supports. They should be open gratings of strong wood strips or iron gratings so as not to interfere with air circulation. Lumber kiln trucks generally consist of several 2-wheel units as shown in Figure 51. Each unit supports one end of two crossbeams under the stickers. If kiln trucks are used, they should be lubricated frequently because kiln conditions cause corrosion that makes the wheels hard to turn.

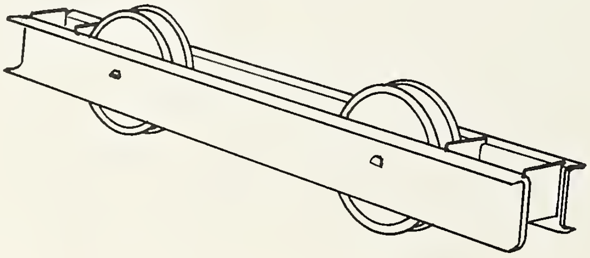


Figure 51. --Two-wheel kiln truck unit.

In case kiln trucks and tracks are not practical, solid load supports similar to those in the hot-air kiln can be used if properly raised above the floor.

Metal sheets or baffles of low height can be installed between the central and side heating coils below the tracks. They should extend down from the bottom of the tracks to 6 inches below the lowest heating coil, and they should run the full length of the kiln.

Steam Coils, Other Heaters, and Steam Spray

This type of kiln and other more modern kilns will operate much better if heat and humidity spray can be supplied by steam. This requires a small low-pressure boiler of 1.5 to 2.0 boiler horsepower capacity per thousand board feet of lumber. Steam available from a larger boiler can be reduced to lower pressure for kiln heating. In some cases, exhaust steam from another process may be used.

The best form of heater for the natural circulation kiln shown is iron pipe coils, but radiators also can be used. If special fin-type coils are available, fewer feet of coil will be needed. The multiple return-bend type of coil shown in Figure 50 is a good design. The supply line feeds steam into the upper header at the front of the kiln. The steam flows to the rear of the kiln, then back to the lower header near the door. Since the heat is given up to the coils by the condensing of the steam, there must be a pitch of 1/8 to 1/4 inch per foot of coil length to drain the condensate back to the lower header. From there it is drained through a trap and returned to the boiler. Installation of such a heating system requires a trained steamfitter.

The coils should be divided into one central unit and two side units as shown (Figure 50). A hand shut-off valve should be between the supply and the central coil unit. There should be another hand valve for the two side units. At the start of drying, the two side units are turned on and the central unit turned off. The air circulation is as shown by the arrows. Later in the drying process, the side coils are shut off and the central unit is turned on.

A steam-heated kiln should have a steam spray line. This is a pipe running the full length of the kiln, with holes drilled at intervals along the bottom of the pipe. A single pipe would give enough spray for a kiln of this size, but air circulation at the start is helped by the two-pipe spray line shown in Figure 50. Both pipes are connected to a low-pressure steam supply line with a single shut-off valve. The other end of each spray line is left open.

It might be possible to construct a natural circulation kiln using a number of small flue pipes in place of the steam coils. The problems involved in such a kiln, to avoid danger of fire, to prevent surface checking and honeycombing, and to insure uniform drying along the length of the lumber, are very great. A forced circulation kiln with the flue pipes or other heat exchanger placed in some other location is a better arrangement. A small natural circulation furnace kiln with heat and moisture supplied by sand trays has been developed in India, and is described in Indian Forest Bulletin No. 26 (Appendix A).

A simple steam-heated natural circulation kiln normally has heating and steam spray valves controlled by hand shut-off valves. Automatic on-and-off valves can be used with this type of kiln, however. Early kilns in the United States had manual control. They often used recording instruments that showed both the dry-bulb temperature and wet-bulb temperature on a clock-operated chart. The bulbs for the thermometers were located inside of the kiln, with the instrument located on the end of the kiln. Flexible tubing connects the bulbs with the recorder. Nonrecording thermometers of the long tube and bulb type are also available. A pair of regular thermometers can be used instead of these if the drying temperature is not too high for someone to enter the kiln, or a special maximum-type wet- and dry-bulb hygrometer can be lowered through roof vents.

Loading

By use of the kiln trucks and the track, one kiln load of lumber can be piled or unpiled as another is being dried. Doors at both ends of the kiln make it easy to change loads. Another arrangement is to use a sidetrack at the loading end of the kiln. This may be connected to the kiln track by either a switch or a transfer car. When the wheels of the kiln truck are as shown in Figure 51 and the crossbeams are not fastened to them, the separate parts can be picked up and returned to the loading area without the need for switches and return track.

The method of piling lumber for a natural circulation kiln is shown in Figure 50. Only one kind of wood and one thickness should be piled in a single kiln charge. Vertical flues should be left between groups of boards. The flues should be as straight sided as possible. At least a 4-inch flue width should be allowed for every 12 to 15 inches of board width. A small space, about 1/2 inch, between boards helps to dry the wood faster. The outside of each load should also be kept as straight as possible. Stickers should be spaced not more than 2 feet apart. They should be fully supported by beams underneath and should be in perfect vertical alinement. The boards in each layer of the pile should be all the same length or box piled (Figure 31).

Operation

For easy drying softwoods, soft hardwoods, or dense hardwoods that have been fully air dried, a kiln of this kind can be operated by experience. A few test runs will show what is the best drying procedure for each kind and size of wood. Dense hardwoods that are likely to check or honeycomb should be dried on a prescribed kiln schedule. To follow such a schedule, kiln samples are required. Information on kiln sample procedure, kiln schedules, and the extra equipment needed to carry out this method of operation is discussed later in this publication. The samples should be placed in the load when it is piled.

At the start of drying all doors and vents are closed. The two side coils are turned on to start the heating. After the kiln has warmed up to the operating temperature for the first half of the drying, the steam spray should be turned on a little. Condensation of moisture on the cold lumber should be avoided, but the spray should be turned on enough to prevent checking.

After the lumber is warm, the side coils and the steam spray should be turned on or off as needed to keep the temperature and relative humidity as desired during the first part of the run. Too low a relative humidity causes checking. Too high a temperature causes honeycombing. After about one-fourth to one-third of the total drying time, relative humidity can be lowered slightly by not using the steam spray as often. Later the vents can be opened slightly to further reduce the relative humidity.

After half of the drying time has passed, the steam spray can be shut off completely and the vents and fresh air dampers opened. The side coils can be shut off and the center coils turned on with enough heat to reach some intermediate temperature. The air circulation will be the reverse of that shown in Figure 50. The lumber should begin to dry more uniformly. During the last quarter of drying, after the lumber is below 20 percent moisture content, more heat can be used to bring the kiln up to a final temperature of 160^{o} F. In some cases higher temperatures of 180^{o} or 200^{o}F. can be used during the final quarter of drying, and both central and side coils may be turned on to reach these temperatures. They should not be used together until after the central coil has been used one or more days alone. High final temperatures should not be used on woods that warp badly. The drying period must not be too long or the wood may come to too low a moisture content for its use. Such overdry wood can cause trouble by swelling later.

The best temperatures, relative humidities, and times for each step of operation described above will be different for each kind of wood and thickness. A simple record should be kept for each kiln charge, showing day of drying, dry-bulb temperature, wet-bulb temperature, and wet-bulb depression. Remarks on quality of dried wood also should be shown. After a period of operation, the records for a particular species and size can be compared and the best procedures selected for further commercial drying of this item.

Larger Natural Circulation Kilns

Natural circulation kilns can be small, medium, large, or very large. The larger kilns can be charge-operated (all lumber put in or taken out at one time) or operated progressively (one dry truckload taken out at one end as a green truckload is put in the other end).

Large natural circulation kilns were used successfully in the United States in the early stages of the kiln-drying industry. If industrial conditions develop in other countries so that steam will be available, but not power for fans and other electrical equipment, larger natural circulation kilns might be useful. Large natural circulation kilns can be operated progressively, but such operation does not permit good relief of drying stresses in the lumber.

SMALL FORCED-CIRCULATION FURNACE KILN

A small furnace-type lumber dry kiln has been constructed and operated at the U.S. Forest Products Laboratory. It is suitable for small sawmills and woodworking plants where electricity is available but no steam. It can dry air-dried lumber or softwoods for general construction, but it does not do as good a job of drying as a modern kiln with both steam and forced air circulation. Green lumber of the dense, slow-drying type may have to be air dried first before being dried in this kiln.

This kiln uses a simple hot-air house furnace for heat, fans for the circulation of air through the lumber pile and the furnace jacket, and a water spray for humidification. The kiln capacity is 4,000 board feet. The type of furnace used is relatively cheap, easy to install, and requires no complicated equipment or machinery. It has a cast iron fire pot in which wood or coal is burned. A sheet metal jacket and hood enclose an air space around the fire pot. This air is heated and circulated into the kiln to dry the lumber. The kiln is not suited for natural circulation drying, even with a blower to return the cold air to the furnace jacket. It requires two fans and complete baffling to force the heated air through the lumber. The water-spray system also is the only way proper humidification can be obtained if steam is not available.

The Kiln Building

The general design of the forced circulation furnace kiln is shown in Figure 52. This is an end view showing general details of construction. A drying chamber takes slightly more than half the width. The furnace is in a slightly smaller room. In warmer climates the furnace could even be out of doors, under a shed roof. The furnace is located about halfway from the front to the back of the kiln. An opening at the bottom of the wall between the two rooms allows the cold air to flow from the drying chamber into the furnace jacket. Another opening near the top of the wall is for the hot-air duct into the drying chamber.

Two fans, one on either side of the hot air duct, are mounted above the lumber to blow the air across the top of the load and down into the space beside the lumber pile. Baffles beneath the fans and down to the top of the load force the air through the pile, into the other side space, and up to the fans again. Only a portion of the air goes through the furnace ducts.

The foundation and floor are poured concrete. The walls are cement blocks with cinder or low-density aggregate set in tempered mortar, or of wood construction as described below. Seasoned wood is used for the fan and baffle supports, kiln ceiling, and roof. It also is used for the piling guide and load support. The construction shown uses clear glass blocks for a thermometer observation window. This window is not entirely necessary. The wall between the drying compartment and the furnace room should be of the same construction as the other kiln walls, with kiln paint or a vapor barrier on the drying chamber side.

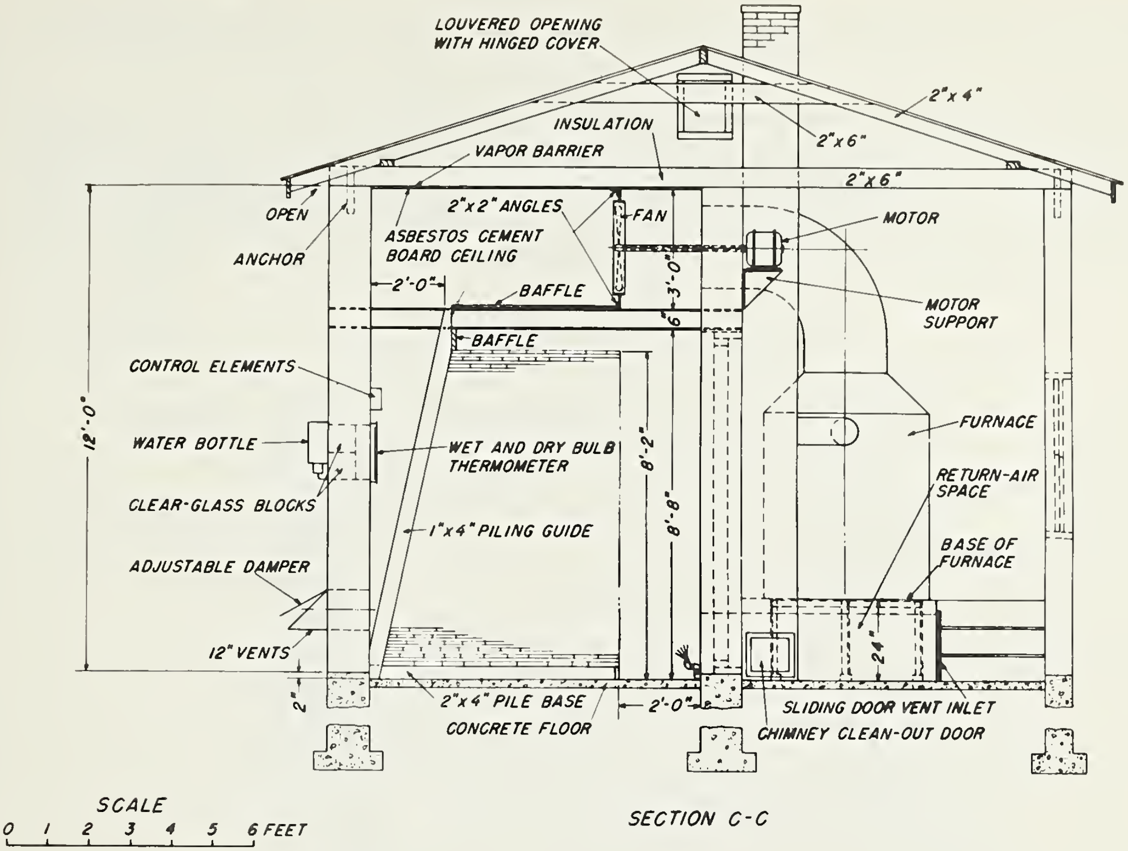


Figure 52. --Design of a small forced-circulation furnace kiln.

Wood walls. --Because of good structural and insulating value, wood can be used to build kiln walls. Wood walls do not need to be as thick as masonry walls. The wood should be seasoned at least to 20 percent moisture content, but 12 percent moisture content would be better. If good plans are carefully followed in building and if the wood is protected from moisture by good moisture barriers, a wood kiln will last from 7 to 15 years. Wood kiln walls are of two types --frame or crib.

Frame-type wood walls are constructed of 2- by 6-inch studs 16 inches on center, covered with 1-inch sheathing inside and with sheathing and bevel or drop siding outside (Figure 53).

For insulation, 4-inch-thick rock wool batts or roll-type material can be applied between the studs before the vapor barrier is applied, or the air space in the completed wall can be filled with vermiculite or loose rock wool. A vapor barrier consisting of vaporproof roll roofing or paper coated on both sides with high-melting-point asphalt should be applied to the inside face of the studs before the inner sheathing is applied. The vapor barrier should be applied vertically and all joints should be well sealed. Kiln paint will not make a good vapor barrier on the inside sheathing of the wall. If sheathing paper is used between the siding and sheathing in the outside face of the wall, it should be a waterproof but not vaporproof material, such as tar paper or slater's felt.

Crib or laminated walls, consisting generally of 2- by 6-inch stock laid flat (one on top of another and well nailed), are sometimes used where lumber is plentiful and inexpensive (Figure 53). This wall, installed with drop siding outside, has good resistance to heat but should be protected against moisture by a vapor barrier or asphaltic kiln paint on the inner face.

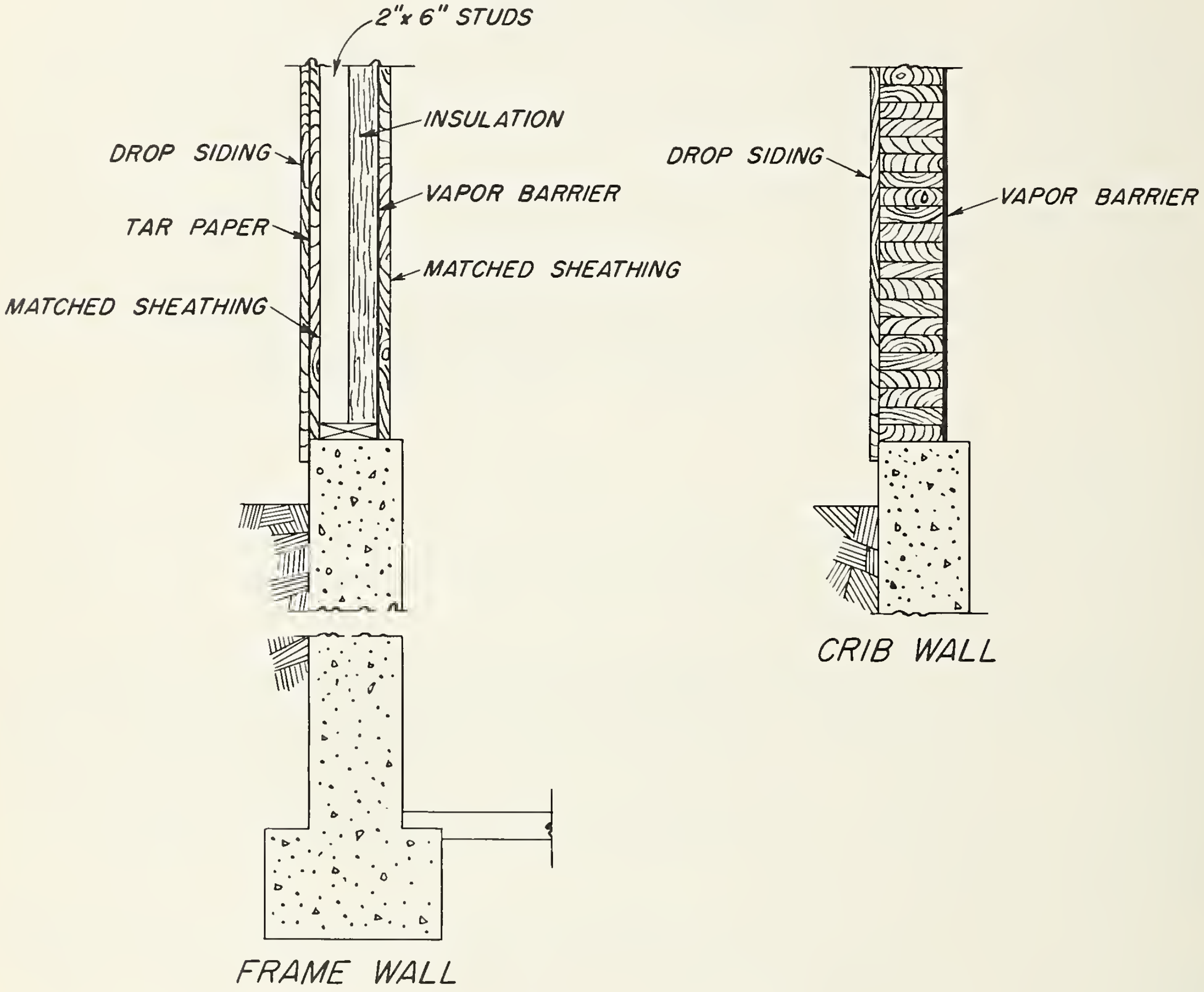
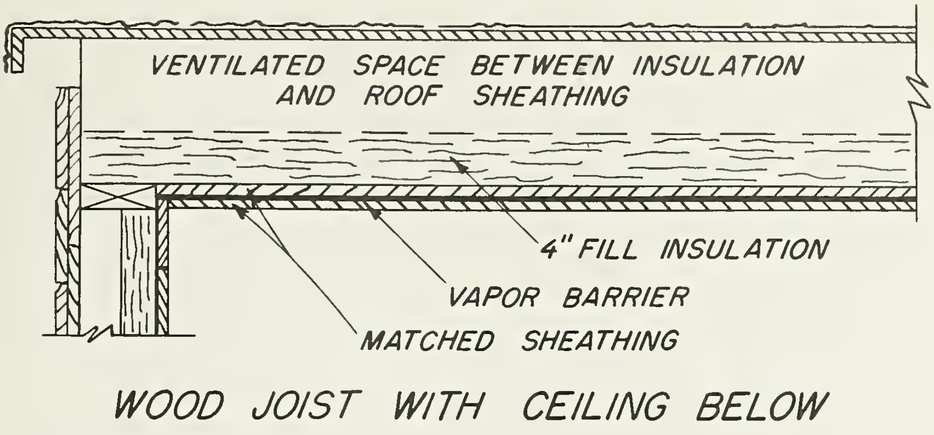


Figure 53.--Types of wood walls.

Wood roofs.--Kiln roofs of wood are relatively cheap to construct and use available material. One frame type of flat roof (Figure 54, top) attaches the roof and the ceiling to the same frame. Joists, 2 by 10 inches in size or larger, support a layer of 1-inch boards on top and another similar layer on the bottom with a space between. The joists should be spaced 16 to 24 inches on centers, with at least one row of bridging. The lower half of the spaces between the ceiling and the roof should be filled with some insulating material, such as dry sawdust or vermiculite. The upper half of the spaces should be ventilated. A vapor barrier should be used in the ceiling.



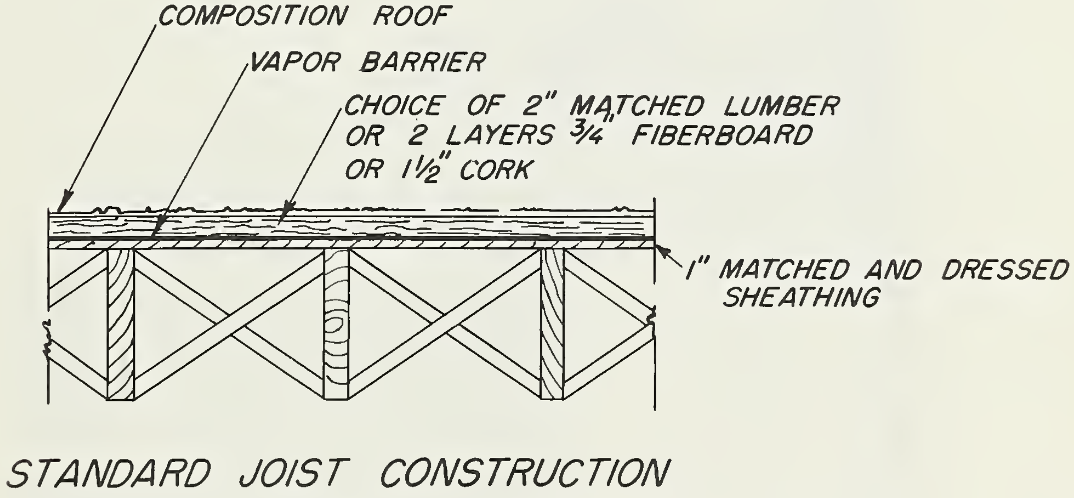


Figure 54.--Types of wood roofs.

Another type of frame construction uses separate joists to support a flat roof considerably above the ceiling or rafters to support a pitched roof. A thatched roof can be used for this latter type of construction to replace the board roof. In this case, a ridgepole and light framing is required to elevate the thatched roof above the ceiling and to obtain an adequate pitch. A corrugated sheet metal roof could be used in place of the thatching, but the space between ceiling and roof must be fully vented.

A less desirable type of frame construction for roof and ceiling consists of two layers of 1-inch boards with a material such as roll roofing between, and weatherproof, but not vapor tight, roll roofing on top. The roof can be made more efficient by using 2 inches or more of insulation above the vapor barrier, then applying a layer of roll roofing or a composition roof. Figure 54, bottom, shows this type of roof and the details of bridging between joists.

Doors.--A kiln door should be strong, light, easy to handle, resistant to corrosive actions, and have high insulating properties. Modern kiln doors are usually constructed of wood or lightweight metal in combination with some insulating material. The best kiln doors are large panels that fit directly into special notched door frames. The frames hold the doors tight against the gasket material. These doors are lifted and moved by special door lifters hung on rollers that operate on a rail over the door opening. A door of this type on a small furnace kiln is shown in Figure 55. This door could be used for track-type operation. Small inspection doors should be fitted into the bottom of the large doors, so that the kiln operator can enter the kiln without opening the large door. The small door latch should open from the inside as well as the outside of the kiln, so no man can be locked inside of a kiln. Doors, just as walls, should have a vapor barrier under the first layer of material on the side facing the kiln.

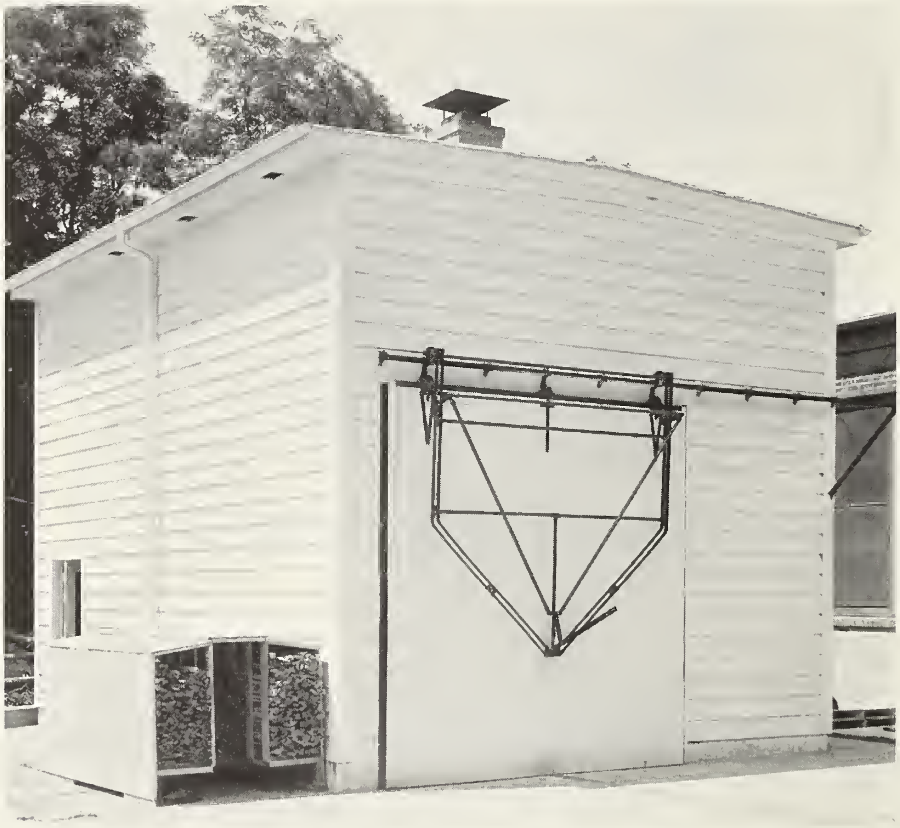


Figure 55.--Small wooden furnace kiln with panel door and door lifter. Roofed sticker rack at side.

Fans and vents.--Most of the kiln air is blown from one side (the entering-air side) of the kiln to the other (the leaving-air side) by two overhead fans mounted in a vertical fan baffle directly over one edge of the load (Figure 52). The fans are 24 inches in diameter and of the propellor type. Each fan is housed in a rim and frame that carries one of the shaft bearings. Since most electric motors will not stay in good condition under dry kiln conditions of high temperatures and high humidities, they should be placed in the furnace room or outside under small roofs if there is no furnace room. Each motor should be firmly attached to a solid mount. There should be a good seal where the shaft goes through the wall. The exact size and type of fan is not important. The 24-inch fans shown, when connected to 1/2 horsepower motors and operated at 1,140 revolutions per minute, deliver 10,000 cubic feet of air per minute. They produce an air velocity through the load of 200 feet per minute, enough for ordinary good drying.

To make all the kiln air go through the lumber pile, the baffle in which the fans are placed should extend to the ends of the kiln and from the fan floor baffle to the ceiling. The baffles and ceiling can be of wood or they can be asbestos-cement board for extra fire protection. A canvas or hinged wood baffle should extend from the fan floor to the top of the load and be held there with weights. If there is much space between the end of the load and the end of the kiln, temporary wood panels should be inserted as vertical baffles.

The bearings of the fan shaft and motors should be lubricated regularly. Some kilns use oil tubes leading to the bearings from oil cups located outside of the drying chamber. Others use special lubricating fittings for high temperature grease from a grease gun.

The majority of kiln fans in the United States are driven by electric motors, but any kind of power may be used. To be effective, kiln fans must be able to force air through the load with a velocity of 50 feet per minute or more. This requires a high-speed fan which requires considerable power. Electricity can be generated by windmills, waterwheels, or turbines. In a few locations, these sources of energy could be used directly. Where sawmills are powered by steam or internal-combustion engines (gasoline, diesel, or distillate oil), belts connected to main drive shaft pulleys could be used to turn the fans or generate electricity.

Two 12-inch pipe vents extend through the outside wall. Their location near the bottom of the wall is merely for convenience in adjusting the dampers and for minimizing drip of condensed moisture. The outlets must be located some place on the pressure side of the fans.

A fresh-air inlet with a sliding door control lets air into the lower part of the furnace jacket.

The furnace and water spray.--The furnace shown in Figure 52 is one of the simplest American home heating furnaces. It may have a 20-inch cast iron fire pot or a welded steel firebox with refractory brick lining. A larger outer jacket, hood, and hot-air duct have double galvanized iron walls with asbestos insulation between. The furnace is placed on a strong base about 2 feet above the floor. Openings in the base allow air from the bottom of the kiln or fresh air to flow up around the firepot and into the kiln.

A furnace for a 4,000-board foot kiln should deliver 150,000 or more British thermal units per hour.

Fuel for the furnace should be coal or hardwood blocks of a uniform size for constant temperature control during drying. Properly fed petroleum fuel oil or natural gas could be used, if available. The products of combustion should be discharged through a flue pipe into a chimney. The furnace should have a draft control and a damper in the flue pipe for proper control and efficient use of the fuel.

Other types of furnaces probably could be used, such as one in which the firebox is refractory brick and the heat transfer flues and furnace jacket also are of brick. Any such furnace should have a tight firebox so that none of the burning gases get into the kiln air. It also should have a good flue design so that most of the heat is transferred to the air in the ducts.

The method of humidification consists of three water-spray nozzles mounted on a 1/2-inch pipe. This pipe is located, as shown in Figure 52, on the floor next to the furnace-room wall. The sprays are directed upward. Since the sprays are on the leaving-air side of the load, their direction conforms to the direction of the air flow back to the fans. The best spray nozzle is a fan-shaped type that delivers a fine spray under a water pressure of about 50 pounds per square inch. Higher water pressures would be better.

Loading and Operating

The drying chamber of the kiln shown in Figure 52 is 17 feet long, 12 feet high, and 8 feet wide. The lumber pile is 16 feet long, 8 feet high, 6 feet wide at the bottom, and 4 feet wide at the top. There is no large air space under the load. Dry 2 by 4's are placed flat every 2 feet along the length, and the rows of stickers alined above them. A special piling guide of 1- by 4-inch boards at each support provides a sloping face on the entering-air side of the load and indicates sticker spacing and alinement. Sloping the load helps to get a uniform flow of air across the whole pile. This is needed for uniform drying. The 2-foot-wide space at the top of the load and on the leaving-air side are needed also. Do not try to increase the capacity of the kiln by building wider loads. If greater capacity is needed, the whole drying chamber should be enlarged or more than one kiln built.

As with the piling for other kilns, only one species and one thickness should be kiln dried at a time. If there are small differences in thickness, all the boards in one layer should be as close as possible to the same thickness. Lumber that is not all the same length should be box piled. If all the lumber is shorter than 16 feet, the open space at the end of the pile should be closed with a temporary baffle of plywood, canvas, or sheet metal. Air that by-passes the load does not help to dry the lumber.

As the load is built, some boards are set aside to be cut for kiln samples. The details of the kiln sample procedure are discussed later. Also, kiln sample pockets, as shown in Figure 56, are built into the load on the leaving-air side.

When the pile is completed and the load baffles weighted down, the kiln samples should be weighed and put in place. Then the door fresh-air inlet, and vents should be closed. The fire, which was started about a half hour before the piling is finished, should be made hotter. The fans are started and the kiln is in operation.

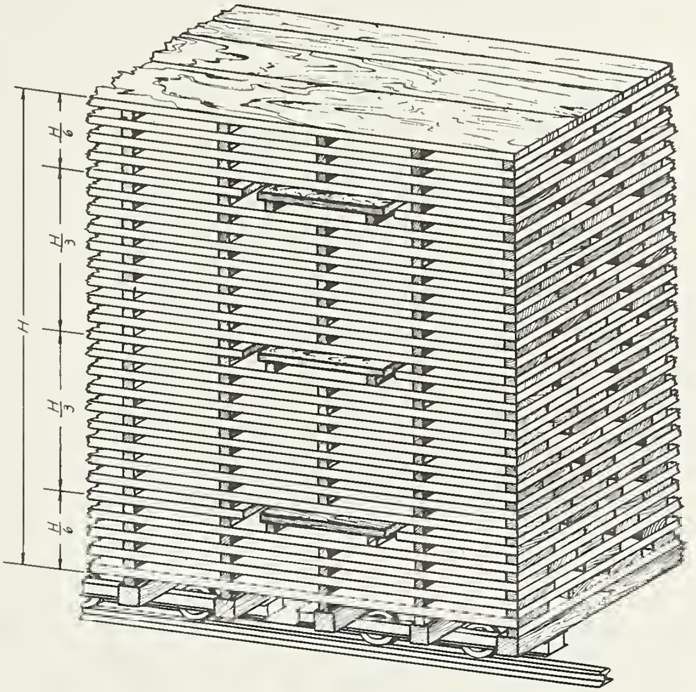


Figure 56. --Kiln sample pockets in kiln load.

For dense hardwoods, the vents are kept closed for about the first one-third of the total drying time. A hot fire is generally needed at the start to warm up the structure and evaporate considerable quantities of moisture. After the first 4 or 5 hours, it may be necessary to use a moderate fire to avoid going above the temperature prescribed for the first part of the drying schedule. For very dense hardwoods it may be necessary to turn on the water sprays occasionally for short periods of time. Generally, however, humidity control should be obtained by keeping the vents closed. A moderate fire can be arranged by cutting down the amount of fuel, reducing the draft, and using the flue damper. For softwoods and easy drying soft hardwoods, faster drying without danger of surface and end checking can sometimes be done by keeping up the hot fire but opening the fresh-air inlet and the outlet vents. These should be opened only a small amount for easy drying hardwoods, but all the way for softwoods. In this case, no water spray would be used.

After one-third of total drying time is up, the vents can be opened slightly for the dense hardwoods. After half of the drying time has passed, a moderate increase in temperature and more venting can be used. After the lumber is below 20 percent moisture content, the kiln can be brought up to a final temperature of 160° or 180°F. The vents should be closed to conserve heat. Leakage lets out the small amounts of water evaporated at this stage of drying. The high temperature is necessary to speed up the movement of moisture from the inside to the surface of the lumber. No water spray should be used when the vents are open, nor during the high final temperature.

At the end of the drying, however, a high relative humidity may be used to relieve stress and set. This treatment requires a great deal of moisture. It may be necessary to cool the kiln down about 20°F. before the high humidity conditioning is started. Then the water sprays are turned on to raise the humidity to 75 percent or higher. See Table 2. A moderate-to-hot fire should be used to keep the temperature up to at least 160°F.

In the previous description, the firing of the furnace and other operations are done by hand. The furnace should be fired as uniformly as possible and the draft and damper should be regulated carefully. Semiautomatic control can be obtained by a simple electrical thermostat that opens and closes the draft of the furnace. A wood-element device also can be used to open and close a valve for the water sprays. The kiln vents would be controlled by hand, however. If an oil or gas burner or a coal stoker is used, a thermostat can control the fuel supply and furnace blower.

Boiler-Type Operation and Larger Furnace Kilns

This forced-circulation furnace kiln would become a cross-circulation steam kiln by substituting a steam boiler for the furnace. A radiator unit would be installed in front of each fan. The water spray would become a steam spray. Some boiler water would be lost during steam spraying; so the fresh water feed to the boiler would have to be automatic. The boiler should be of a capacity of at least 200,000 British thermal units per hour. If a furnace kiln is to be built now and later converted to a steam kiln, the furnace room could be made to match the size of the original drying chamber. All walls could be insulated and vaporproofed. Upon conversion, the central wall would be removed to make a two-track kiln. Unless special glass-wound motors resistant to high temperature and humidity were used, longer shafts would be needed to move the motors outside the kiln.

In the United States, where oil and natural gas are available for fuel, large furnace kilns two or more tracks wide and of considerable length are used to dry softwoods and hardwoods that are air dry. Such kilns are generally not capable of the close humidity control needed for green hardwoods. These kilns are of two types: direct heating or indirect heating.

In the direct type the hot gases produced by burning the fuel are introduced directly in the kiln, mixed with the kiln air, and circulated through the lumber. In the indirect type, the heat is transferred indirectly by flue pipes or other heat exchangers and the products of combustion are discharged from stacks outside of the kiln. The discussion of such large furnace kilns is beyond the scope of this publication. Such kilns should not be considered if modern steam-heated kilns can be installed.

MODERN STEAM-HEATED INTERNAL-FAN KILNS

In the United States the best type of dry kiln is the steam-heated internal-fan kiln. Dry-bulb temperature and relative humidity are under automatic control. This type of kiln is adaptable to charges as large as 100,000 board feet for most economical drying of softwoods and to small sizes (10,000 to 30,000 board feet) for drying a variety of hardwoods. With some exceptions, the best quality drying can be done by using such equipment to dry the material from the green condition. Sometimes such drying is also the most economical. In other cases, partial air drying or predrying, followed by kiln drying, gives high quality drying at the lowest cost. Such kilns are economical both at producing sawmills and at factories where large quantities of lumber are used to make furniture and other items.

The heating coils of such kilns are divided into small units so that a maximum or a minimum of heat can be used. Automatic instruments, operated by either compressed air or electricity, control the amount and uniform distribution of heat. They also control the relative humidity of the air by steam spray and ventilation. Fans may be 2- or 4-bladed, multiblade disk, or propeller type. In some kilns, special heat- and moisture-resistant fan motors are used within the kiln. Others have short fan shafts with motors outside the kiln. In still others the fans are all on a single long shaft connected to a large motor outside the kiln. A special fan-baffle arrangement directs the air into the side plenum chamber and through the lumber. In all types, the motors and fans can be reversed so that reversible air circulation can be obtained. Kilns with more than one track have additional heating units (booster coils) between the loads.

A variety of building materials are being used for modern kilns of all sizes. Poured concrete is used for foundations and floors, but not for kiln walls. For the walls, it would have low insulating value, and would be subject to large cracks. Open-type concrete blocks containing lightweight aggregate (blast furnace slag, hard-burned cinders, or naturally lightweight minerals) are used. Wood walls of heavy frame construction are also used in many modern kilns in regions where Douglas-fir is grown. The heartwood of this species is low in moisture content and naturally durable. Decay of wood in kiln structures is not a problem except where water collects near the bottom in a kiln that is not used continuously. Deterioration under heat, however, may result in loss of strength in 7 to 15 years. The best material and type of construction for kiln roofs has not been determined, but light-aggregate concrete slabs with heavy vapor barrier paint underneath appear to be amont the best. They may have extra insulation on top and a weatherproof top. Steel beam supports and expansion joints are necessary for large roofs.

A new type of kiln structure, the prefabricated insulated panel kiln (Figure 57) is coming into some use. Prefabrication allows manufacture and shipment of all necessary kiln parts and equipment by one manufacturer. Size can be varied to meet the buyer's needs. Special panel joints and sealers are needed where the panels fit together, but these have been developed. Such kilns are considerably more expensive than the set of kiln parts normally shipped by a manufacturer for the user to put in his own building, but they are quicker and generally no more expensive to erect than the customary building. They also avoid the chance of mistakes in design or construction that cost money to change after a kiln is built. They can be dismantled, resold, or moved if economic conditions require.

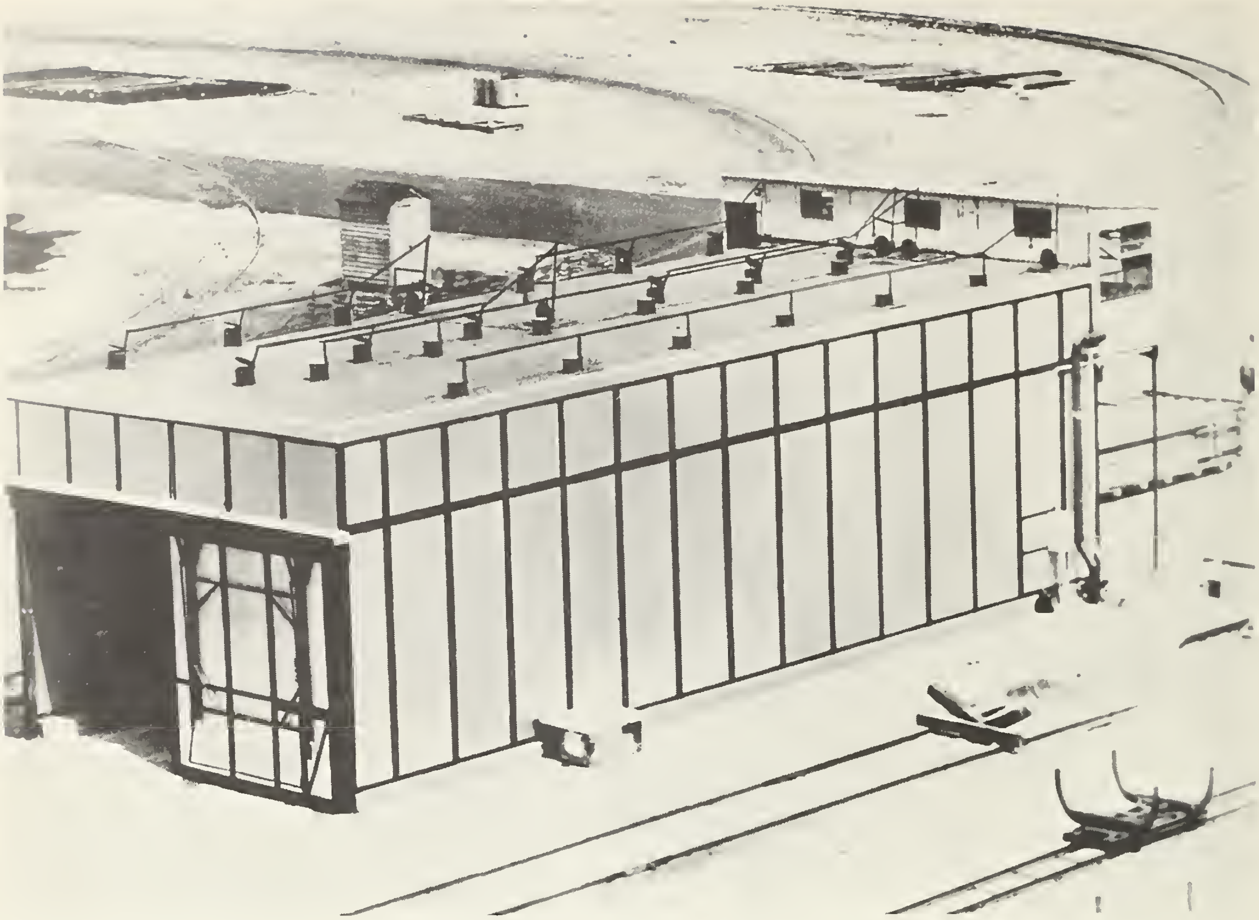


Figure 57.--Prefabricated panel steam-heated internal-fan kiln.

Dry kilns have special requirements of structure not commonly encountered in other buildings. The operating conditions of high temperature and high relative humidity require that the internal equipment also be of special design. It is best, therefore, to purchase dry kiln equipment and kiln building plans from an established kiln manufacturer. An international list of manufacturers of dry kilns and the type of equipment they make has been published by the Food and Agriculture Organization (Appendix A). A partial list of American manufacturers of dry kilns is given in Appendix E.

The comparatively small, completely prefabricated and assembled dry kiln for high temperature drying made by some of the European firms may be of interest to manufacturing firms where small amounts of softwoods will be used to manufacture articles with a large amount of hand labor. Even though such kilns dry lumber rapidly, they have not been adopted in North America because they are not suited for large-scale use at producing sawmills or mass production furniture plants.

STACKING FOR KILN DRYING

To get the highest quality results, good sorting and stacking are necessary with even the most modern kilns. Good sorting is very important in kiln drying. A kiln charge should be composed of the same species; but when several species have similar drying characteristics they can be combined. Green and air-dried lumber should not be mixed in the same kiln charge. The drying conditions and the length of time required to dry the two classes of stock are so different that the efficiency of the kiln would be lowered. In many species, the sapwood boards and the heartwood boards should be sorted and kiln dried separately because of differences in green moisture content. High-quality lumber is usually dried more carefully and to a lower moisture content than low-quality lumber; so sorting by major grade separations -- commons versus clears -- is usually desirable when the lumber is graded.

Lumber to be stacked for kiln drying should be sorted for thickness. Thick stock requires milder kiln conditions of temperature and relative humidity than thinner stock and requires a longer drying time. Occasionally, however, it may be necessary to use lumber of different thicknesses to build a single kiln truckload. Then all the thick boards should be placed in the bottom part of the load and the thinner ones in the top part. The best that can be done with miscut lumber (thicker at one end than at the other) is to stack one course with the thick ends all toward one end of the load, and the next the course with the thick ends the other way. Each kiln truckload should be made of one length lumber if possible.

When the stacking bay where the kiln truckloads are built is equipped with sticker guides to assure the proper location of the stickers and their vertical alinement, very good loads can be built (Figure 58), and the maximum amount of straight, high-quality lumber is produced.

CONTROL OF KILN CONDITIONS

To rapidly dry the lumber to a low moisture content with few drying defects in a dry kiln, the temperature and relative humidity must be carefully controlled. Lack of control can result in complete spoilage of a kiln charge. The chance for loss is greatest when the lumber is green, relatively thick, or of a species that tends to check or collapse. A close degree of control is also needed if the wood must be dried to a precise final moisture content specification, and a complete conditioning job is required to relieve drying stresses at the end of the kiln run.

The temperature and relative humidity conditions that are suitable at each stage of the kiln drying of a particular kind of lumber make up what is known as a kiln drying schedule. The instruments used to measure the relative humidity of outdoor or room air do not operate satisfactorily in high-temperature dry kilns, so the kiln conditions are measured by dry-bulb and wet-bulb thermometers. Automatic kiln control instruments use these also. A simple type of dry-bulb and wet-bulb indicator using etched-stem glass thermometers is shown in Figure 59. This instrument is suitable for mounting

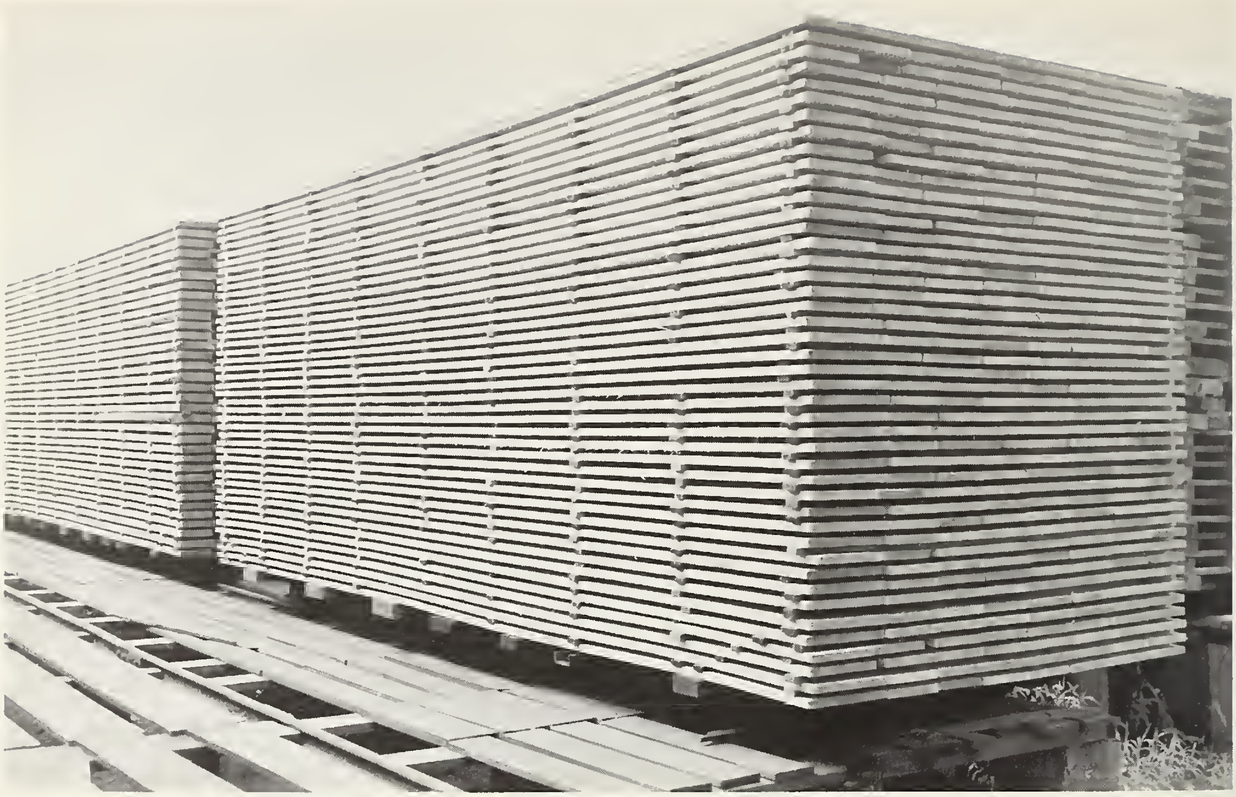


Figure 58.--Well-piled kiln truckload of uniform-thickness lumber.

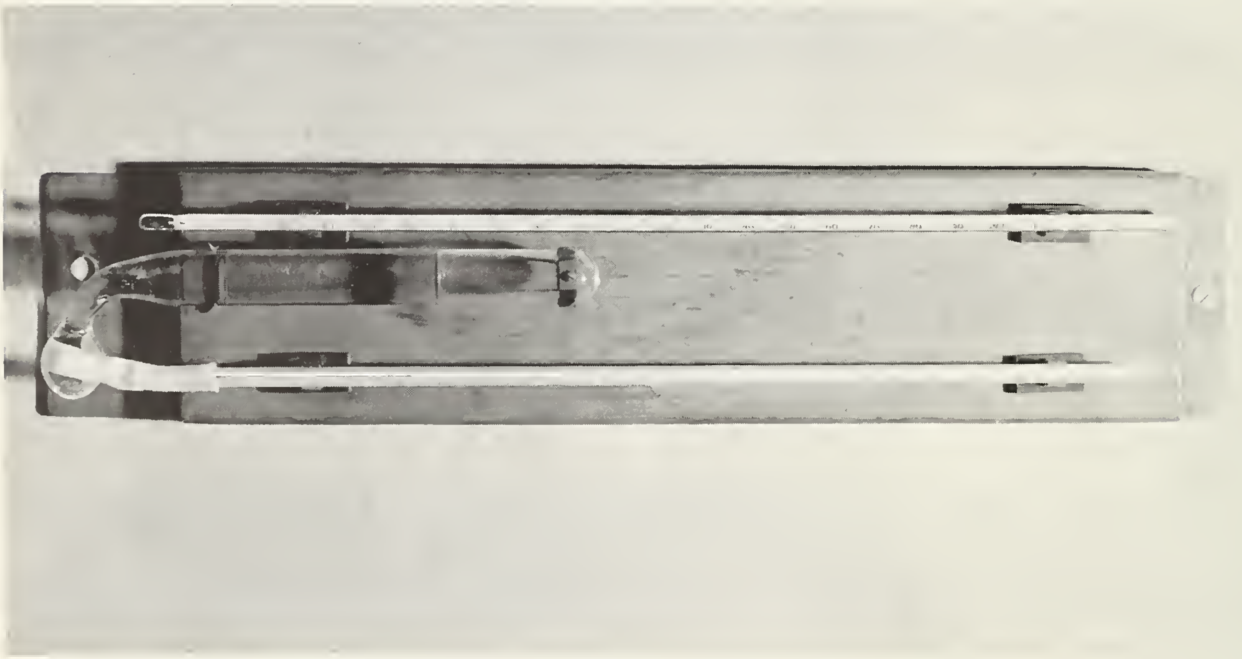


Figure 59.--Dry- and wet-bulb hygrometer with two etched-stem glass thermometers.

behind a kiln window, with a refillable water reservoir outside of the kiln. The following discussion covers the various aspects of dry-bulb temperature and wet-bulb temperature control.

Dry-Bulb Temperature

High temperature causes water to move more rapidly through the wood, and consequently accelerates drying. However, wood generally shrinks more under high temperatures than under low temperatures. Collapse, an excessive shrinkage in certain zones of the wood, is more likely to occur under high temperatures than under low ones. Warping, which is associated with shrinkage, may be more severe under high temperatures. High temperatures also are likely to cause chemical stains, such as kiln burn and brown stain, or may cause general darkening of color. Excessively high temperature may cause some loss in strength. Thus, use of some elevation of temperature is desirable, but it must be kept under control.

Manual control.--The simplest type of temperature control consists in regulating the amount of fuel that is supplied to a firebox or a flame. Manipulation of the draft dampers also helps control where wood waste is burned in a firebox. With gas or oil, enough draft must be used to burn all the fuel. In steam-heated kilns, the temperature can be controlled by adjusting the valves to the pipe coils or radiators by hand. Control of dry-bulb temperature at the exact temperature of the schedule is not necessary, provided the relative humidity or wet-bulb depression is kept under good control.

Automatic or instrument control.--Thermostats are instruments that respond to temperature changes and keep the temperature at a set value. They turn on or shut off the supply of fuel or heat, open or shut dampers, and open or close steam valves.

Thermostats may be self-contained or auxiliary-operated. Self-contained thermostats operate the fuel feed or dampers directly. In an auxiliary-operated thermostat, the pressure or movement generated by the thermostat causes compressed air or electricity to operate the valve. Most of the modern dry kiln thermostats not only control the temperature but are equipped with a pen arm that also records the temperature on a time chart. Such an instrument is called a recorder-controller. Simple thermostats are still satisfactory for control of a low-cost kiln, however.

Wet Bulb Temperature

Control of the wet-bulb temperature in combination with control of dry-bulb temperature establishes the relative humidity in the kiln. Since wood tends to attain a definite moisture content when exposed to a certain temperature and relative humidity, the control of relative humidity is important. The surfaces of a drying piece of wood tend to come to this equilibrium moisture content. Control of relative humidity is particularly important during the early stages of the kiln drying of green lumber. If relative humidity is too low, end and surface checking will occur. Control of both wet-bulb temperature and dry-bulb temperature also is necessary throughout the kiln-drying process if a particular drying schedule is being followed. At the end of drying, good control is necessary for equalizing of moisture content and conditioning to relieve drying stresses.

Manual control. --In the simplest types of dry kilns, opening or closing the vents is the only way of controlling wet-bulb temperature or relative humidity. When more fresh air is let in and more warm moist air is let out, the relative humidity within the kiln is lowered. Since the simplest types of kilns are not equipped with steam sprays or water sprays, the only water vapor in the kiln air is that given off by the lumber itself. To keep relative humidity high, keep the vents closed. At the start of a kiln-drying process, however, moisture may be introduced into the kiln by wetting down the loads of lumber and the interior of the kiln with water. Where steam or water sprays are available, manual control is best accomplished by someone turning the valve on and off as needed.

The difference between the dry-bulb and wet-bulb temperature is the wet-bulb depression. When this value gets too large, the spray should be turned on. A special maximum-type wet- and dry-bulb hygrometer that can be let into a kiln through a roof vent is shown in Figure 60. After being in the kiln about 10 minutes, the instrument is removed and read. Then the mercury is shaken down for another reading. The wick should be clean and the water reservoir filled with rainwater or mineral-free water. For correct determination of wet-bulb temperature, there must be a strong circulation of air over the wet-bulb.

It is generally not good to leave the steam or water spray valves open for long periods of time. Manual control sometimes is exercised by using a needle valve and only opening it part way. When this method is used, the valve seat may have to be replaced frequently.

Automatic control. --The simplest instrument to control wet-bulb temperature is a thermostat with a wick over the element or bulb. To operate automatically, the thermostat with a wick-covered bulb is set at the desired wet-bulb temperature. When the air in the kiln gets too dry, the thermostat turns on the steam or water spray.

A special type of instrument that can be used to control relative humidity is called a wood element hygrostat (Figure 61). A small block or strip of wood is mounted within the kiln so that its shrinking or swelling activates a compressed air or electrical auxiliary power system which, in turn, operates a fuel or steam valve. In the most modern dry kilns, both dry-bulb and wet-bulb temperatures are controlled by an auxiliary operated recorder-controller.

KILN DRYING SCHEDULES

The control of dry-bulb and wet-bulb temperatures within a dry kiln makes it possible to adhere to a drying schedule. By carefully following such a schedule, high quality drying can be done in a short time. A drying schedule consists of a number of dry-bulb temperature and wet-bulb temperature steps.

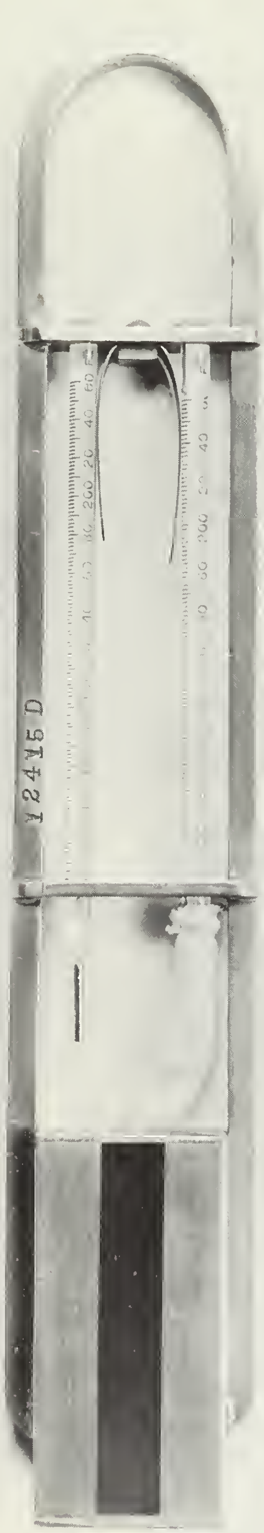


Figure 60. --Special maximum-type wet- and dry-bulb hygrometer.

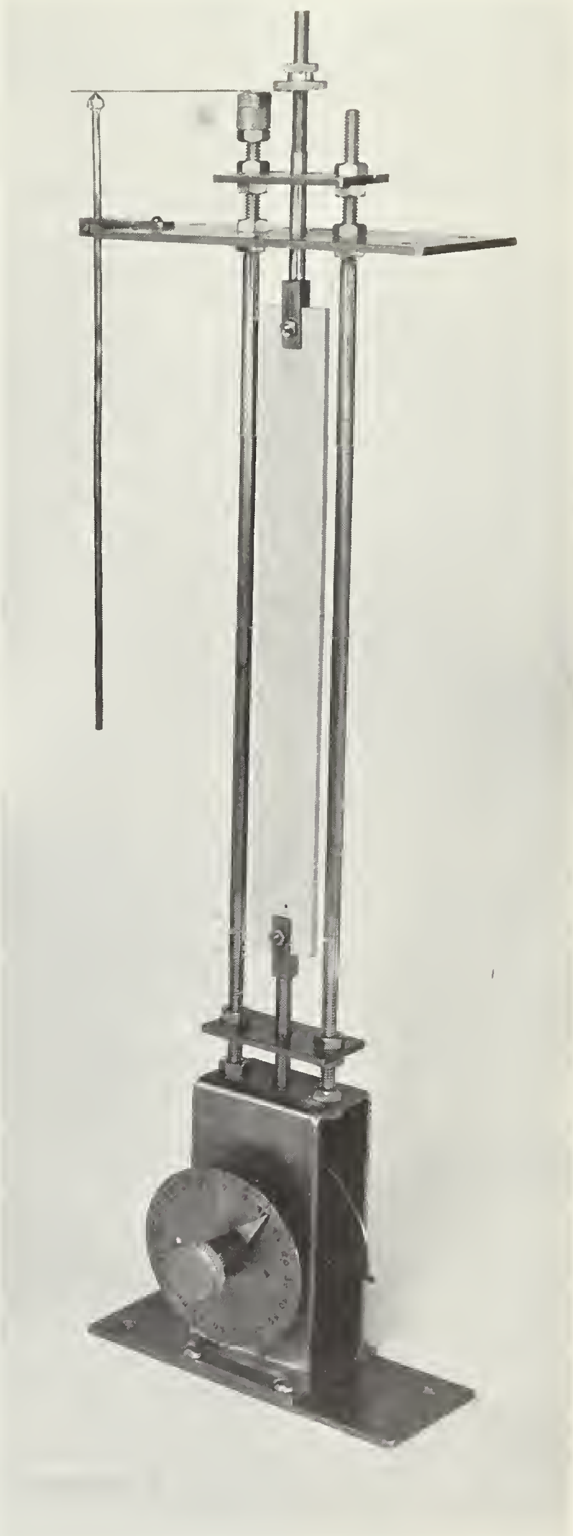


Figure 61. --Wood element hygrostat for relative humidity control.

In moving from one step to the next step, either the dry-bulb temperature, the wet-bulb temperature, or both, may be changed. The relative humidity generally decreases and the temperature increases as drying progresses. At the end of the drying, equalizing and conditioning treatments may be given.

Schedules Based on Moisture Content

Kiln schedules based on the moisture content of the wood give the greatest assurance of drying the lumber without bad effects. The moisture content of a particular board that is in the process of drying is an approximate index of the stresses that develop within this board as it dries. The permissible drying conditions (temperature and relative humidity) should depend largely on the character, magnitude, and distribution of the drying stresses. The high relative humidities recommended for the first steps of kiln drying are primarily for controlling the magnitude of the tensile stress on the surfaces of a board. The low temperatures during the early stages are principally to avoid a weakening effect on the wet interior zones of the piece. Too low relative humidities during the early stages may result in surface checking. Too high temperature at the start of drying may result, later on, in internal checking (honeycombing) or collapse. During the intermediate stages of drying the surface is in compression and can withstand low relative humidities without danger of surface checking. Moderate temperatures still should be used as long as the interior portion of the piece is above 30 percent moisture content. During the later stages, high temperatures can be used in combination with low relative humidities.

If enough drying records and experience are obtained in drying a particular item of lumber, a schedule based on time can be developed. Time schedules will vary, however, with the species, thickness, character of the grain, heartwood or sapwood, and the moisture content at the time of loading into the kiln. They also vary with the type and efficiency of the dry kiln and the final moisture content that is desired. Moisture content schedules are the safest means of kiln drying until considerable experience is gained.

Kiln Samples

Some means of determining moisture content to follow the course of drying is necessary. The most reliable and common method is the use of kiln samples. A kiln sample is a short piece of board 30 inches or more in length that is cut from the lumber as it is being stacked. The number of kiln samples should be at least one for every 5,000 to 8,000 board feet or a minimum of four per kiln charge. Figure 62 shows how kiln samples are cut from boards and where cross sections for the determination of moisture content by the ovendrying method are obtained. Three or more of the boards from which the kiln samples are obtained should represent the wettest and slowest-drying lumber. One should represent the fast-drying boards.

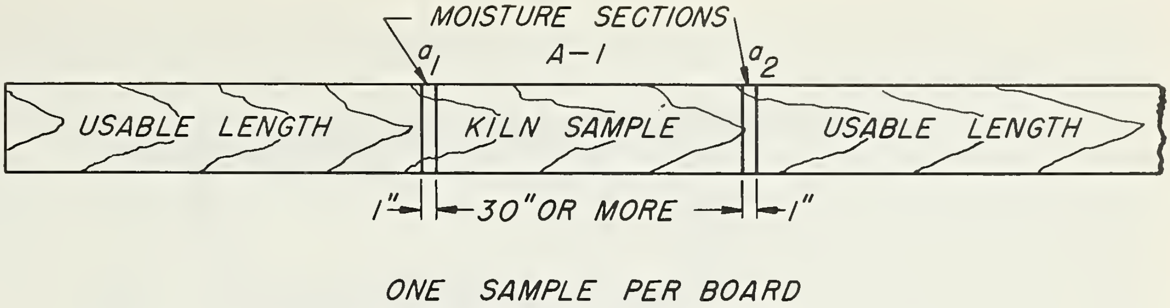


Figure 62. --Method of cutting and numbering kiln samples.

Immediately after cutting, the kiln samples should be end coated and weighed. The weights should be marked upon the kiln samples. The sections for the determination of moisture content should also be weighed promptly. The two sections are usually weighed together, but they can be weighed separately. The weights should be marked on the small sections. Then they should be ovendried at 214° to 221°F. After ovendrying for 12 to 48 hours, these sections are again weighed. Then the sections are ovendried for 4 more hours and reweighed. The lowest weight is the ovendry weight.

A bandsaw, triple beam balance, and drying oven for moisture content sections are shown in Figures 63, 64, and 65. Any oven capable of control at 101° to 105°C. should be satisfactory. A scale weighing up to 20 kilograms with gram graduations, or scale reading in pounds and hundredths of a pound, is suitable for the kiln samples.

Figure 63. --Bandsaw for cutting moisture sections and for drying stress tests.

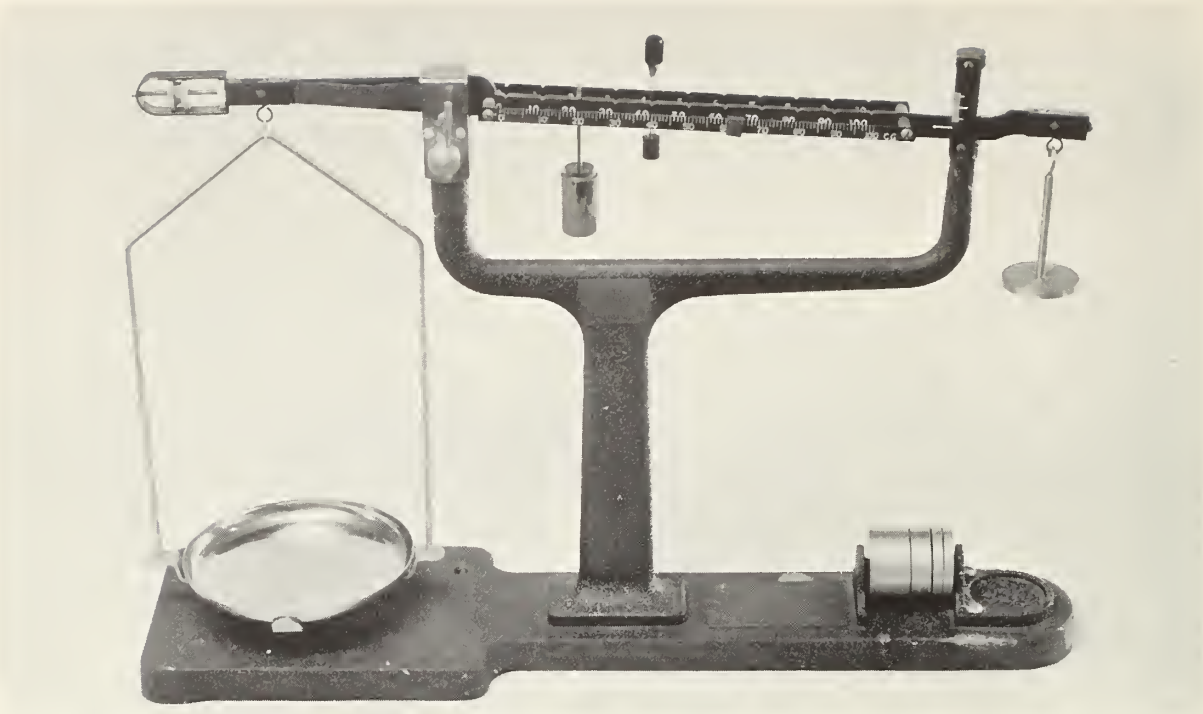


Figure 64.--Triple-beam balance of 1,000-gram capacity for moisture content tests.

Figure 65.--Electric oven for drying moisture sections.

All data are placed on a data sheet such as shown in Figure 66. Formula (1) is used to calculate moisture content on the basis of the ovendry weight.

The average moisture content as determined from these two sections is then used to calculate the ovendry weight of the kiln sample by the following formula:

$$\text{ovendry weight of kiln sample} = \frac{\text{original weight of kiln sample}}{100 + \text{moisture content of sections in percent}} \times 100 \qquad \text{Formula (3)}$$

For example, the original weight of the sample was 4.46 kilograms, and the original moisture content as calculated by the two small sections was 62.2 percent, then the calculated ovendry weight of the sample would be equal to $\frac{4.46}{100 + 62.2} \times 100 = \frac{4.46}{162.2} \times 100 = 2.75$ kilograms.

After the kiln samples have been end coated and weighed, they should be placed in the sample pockets left in the sides of the loads (Figure 56). If the lumber load is not placed in the kiln for several days, the sample pocket should be shielded from sun and wind.

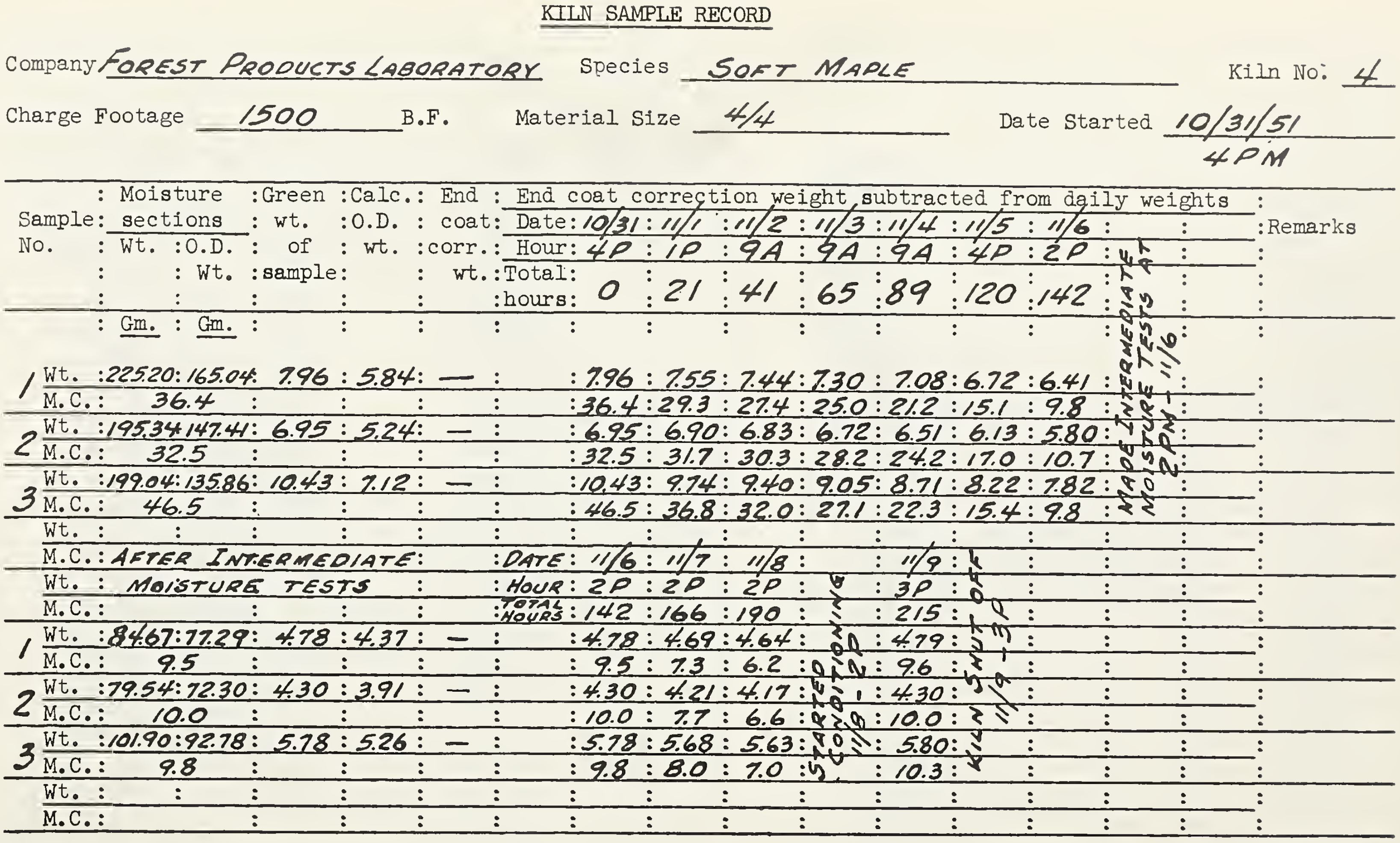
Use of kiln samples in following a schedule.--When drying a charge of lumber by means of a schedule, the samples are removed from the pockets at intervals for weighing. These intervals are daily for short kiln runs or every 2 or 3 days for runs of 2 weeks or more. One or two samples are taken at a time and weighed outside of the kiln. Each sample must be returned to its own sample pocket as soon as it is weighed.

Moisture content of each sample then is determined by the following formula:

$$\text{current moisture content of sample (in percent)} = \frac{\text{current weight} - \text{ovendry weight}}{\text{ovendry weight}} \times 100 \qquad \text{Formula (4)}$$

For example, the current weight of the sample mentioned earlier is 4.11 kilograms. The moisture content is $\frac{4.11 - 2.75}{2.75} \times 100 = 49.5$ percent.

The controlling moisture content for deciding when to change kiln conditions is obtained by finding the average current moisture content of the wetter half of the kiln samples. During the later stages of drying, the wetter half may not include the same samples as at the start, but the moisture content of the wetter half should always be used to establish the kiln conditions corresponding to the appropriate step of the schedule.



KILN SAMPLE RECORD

Company FOREST PRODUCTS LABORATORY Species SOFT MAPLE Kiln No: 4

Charge Footage 1500 B.F. Material Size 4/4 Date Started 10/31/51 4PM

Sample No.		Moisture sections Wt.	Moisture sections O.D. Wt.	Green wt. of sample	Calc. O.D. wt.	End coat corr. wt.	End coat correction weight subtracted from daily weights											Remarks
							Date:	10/31	11/1	11/2	11/3	11/4	11/5	11/6				
							Hour:	4P	1P	9A	9A	9A	4P	2P	MADE INTERMEDIATE MOISTURE TESTS AT 2PM - 11/6			
							Total hours:	0	21	41	65	89	120	142				
		Gm.	Gm.															
1	Wt.	225.20	165.04	7.96	5.84	—		7.96	7.55	7.44	7.30	7.08	6.72	6.41				
	M.C.	36.4						36.4	29.3	27.4	25.0	21.2	15.1	9.8				
2	Wt.	195.34	147.41	6.95	5.24	—		6.95	6.90	6.83	6.72	6.51	6.13	5.80				
	M.C.	32.5						32.5	31.7	30.3	28.2	24.2	17.0	10.7				
3	Wt.	199.04	135.86	10.43	7.12	—		10.43	9.74	9.40	9.05	8.71	8.22	7.82				
	M.C.	46.5						46.5	36.8	32.0	27.1	22.3	15.4	9.8				
	Wt.																	
	M.C.	AFTER INTERMEDIATE					DATE:	11/6	11/7	11/8		11/9	KILN SHUT OFF 11/9 - 3P					
	Wt.	MOISTURE TESTS					HOUR:	2P	2P	2P	STARTED CONDITIONING 11/8 - 2P	3P						
	M.C.						TOTAL HOURS:	142	166	190		215						
1	Wt.	84.67	77.29	4.78	4.37	—		4.78	4.69	4.64		4.79						
	M.C.	9.5						9.5	7.3	6.2		9.6						
2	Wt.	79.54	72.30	4.30	3.91	—		4.30	4.21	4.17		4.30						
	M.C.	10.0						10.0	7.7	6.6		10.0						
3	Wt.	101.90	92.78	5.78	5.26	—		5.78	5.68	5.63		5.80						
	M.C.	9.8						9.8	8.0	7.0		10.3						
	Wt.																	
	M.C.																	

Figure 66.--Data sheet for weights and moisture content of kiln samples.

British Schedules for Both Hardwoods and Softwoods

The kiln schedules developed by the British Forest Products Research Laboratory (Leaflet 42, Appendix A) for a very large number of woods are given in Tables 9 through 13. One of these schedules should be suitable for drying any wood that can be kiln dried. Similar schedules, worked out by Australian, Indian, South African, and other authorities, are referenced in Appendix A. These local schedules should be used wherever they apply. The U. S. Forest Products Laboratory has developed its own schedules for North American woods. These have been designed to dry wood at a faster rate. In situations where the most modern kilns are available, or where the wood must be dried to a low moisture content, the Dry Kiln Operator's Manual (Appendix A) should be studied.

Table 9. --Kiln schedule "A" for timbers that must not darken or that warp badly, but do not check[1]

Moisture content at start of step	Dry-bulb temperature	Wet-bulb temperature	Relative humidity (approx.)
Percent	°F.	°F.	Percent
Green	95	87	70
60	95	83	60
40	100	84	50
30	110	88	40
20	120	92	35
15	140	105	30

[1] British Forest Products Research Laboratory Leaflet No. 42 (Appendix A).

Table 10.--Low-temperature schedules "B," "C," and "D," for timbers that check[1]

Moisture content at start of step	Dry-bulb temperature	Wet-bulb temperature	Relative humidity (approx.)
Percent	°F.	°F.	Percent
SCHEDULE B			
Green	105	101	85
40	105	99	80
30	110	102	75
25	115	105	70
20	130	115	60
15	140	118	50
SCHEDULE C			
Green	105	101	85
60	105	99	80
40	110	102	75
35	110	100	70
30	115	103	65
25	125	109	60
20	140	118	50
15	150	121	40
SCHEDULE D			
Green	105	101	85
60	105	99	80
40	105	96	70
35	110	97	60
30	115	97	50
25	125	101	40
20	140	105	30
15	150	112	30

[1] British Forest Products Research Laboratory Leaflet No. 42 (Appendix A).

Table 11. --Kiln schedules "E," "F," and "G," mostly for moderate-drying hardwoods [1]

Moisture content at start of step	Dry-bulb temperature	Wet-bulb temperature	Relative humidity (approx.)
Percent	°F.	°F.	Percent
SCHEDULE E			
Green	120	115	85
60	120	113	80
40	125	116	75
30	130	117	65
25	140	120	55
20	155	127	45
15	170	136	40
SCHEDULE F			
Green	120	111	75
60	120	109	70
40	125	109	60
30	130	109	50
25	140	115	45
20	155	124	40
15	170	136	40
SCHEDULE G			
Green	120	115	85
60	120	113	80
40	130	123	80
30	140	131	75
25	160	146	70
20	170	147	55
15	180	144	40

[1] British Forest Products Research Laboratory Leaflet No. 42 (Appendix A).

Table 12.--Kiln schedules "H," and "J," for easy drying hardwoods and some softwoods[1]

Moisture content at start of step	Dry-bulb temperature	Wet-bulb temperature	Relative humidity (approx.)
Percent	°F.	°F.	Percent
SCHEDULE H			
Green	135	127	80
50	135	126	75
40	140	126	65
30	150	129	55
20	170	136	40
SCHEDULE J			
Green	135	123	70
50	135	119	60
40	140	118	50
30	150	121	40
20	170	127	30

[1] British Forest Products Research Laboratory Leaflet No. 42 (Appendix A).

Table 13.--Kiln schedules "K," "L," and "M" for easy drying softwoods[1]

Moisture content at start of step	Dry-bulb temperature	Wet-bulb temperature	Relative humidity (approx.)
Percent	°F.	°F.	Percent
SCHEDULE K			
Green	160	151	80
50	170	156	70
30	180	159	60
20	190	153	40
SCHEDULE L			
Green	180	165	70
40	200	162	40
SCHEDULE M			
Green	200	184	70
50	210	179	50

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[1] British Forest Products Research Laboratory Leaflet No. 42 (Appendix A).

Table 14 is an index of the British schedule to use for each wood. The schedule shown is for 1-inch or slightly thicker lumber. The relative humidity at each stage of drying should be 5 percent higher for 2-inch material or 10 percent higher for 3-inch dimension. The information in Table 2 should be used to find the wet-bulb depression for the higher relative humidity values at the desired dry-bulb temperature. Subtract the wet-bulb depression from the dry-bulb temperature to obtain the wet-bulb temperature at which to run the kiln. The entire kiln schedule should be worked out and written down on a card before the drying is started. This card can be posted near the kiln controls during the drying and afterward can be saved for drying the same kind of material in the future. Notes about the results of the drying can be written on the back of the card, and slight changes can be made in the schedule if necessary.

Table 14.--Index of British schedules for kiln drying lumber[1]

Timber		Schedule[2]
Botanical name	Commercial name	
Abies alba	Fir, silver	K
Abies amabilis	Fir, amabilis	L
Abies balsamea	Fir, balsam	L
Abies grandis	Fir, grand	L
Abies lasiocarpa	Fir, alpine	L
Abies procera	Fir, noble	L
Acacia melanoxylon	Blackwood, Australian	E
Acacia mollissima	Wattle, black	A
Acer platanoides	Maple, Norway	E
Acer pseudoplatanus	Sycamore	[3]E, A
Acer rubrum	Maple, soft	E
Acer saccharinum	Maple, soft	E
Acer saccharum	Maple, rock	E
Adina cordifolia	Haldu	E
	Kanluang	E
	Kwao	E
Aesculus hippocastanum	Horse-chestnut, European	H
Aextoxicon punctatum	Olivillo	E
Afrormosia elata	Afrormosia	J
	Kokrodua	J
Afzelia spp.	Afzelia	E
	Doussié	E
Agathis spp.	Kauri, Queensland	J
Agathis australis	Kauri, New Zealand	J
Albizzia spp.	Albizzia, West African	F
	Okuro	F

See footnotes at end of table.

Table 14.--Index of British schedules for kiln drying lumber[1]--Continued

Timber		Schedule[2]
Botanical name	Commercial name	
Albizzia grandibracteata	Nongo	F
Albizzia lebbeck	Kokko	E
Alexa leiopetala	Hiairiballi	B
Alnus glutinosa	Alder, common	J
Alnus rubra	Alder, red	J
Alstonia congensis	Alstonia	H
	Mujua	H
Alstonia scholaris	Shaitan wood	H
Amblygonocarpus obtusangulus	Banga wanga	B
Anacardium excelsum	Espavel	E
Aningueria altissima	Mukangu	C
Anisoptera spp.	Krabak	E
	Mersawa	E
Anogeissus acuminata	Yon	C
Antiaris africana	Antiaris	A
Apodytes dimidiata	Mugonyone	C
Araucaria angustifolia	"Pine, Parana"	D
Araucaria araucana	"Pine, Chile"	J
Araucaria cunninghamii	"Hoop pine"	J
Aspidosperma spp.	Peroba rosa	E
Aucoumea klaineana	Gaboon	E
	Mahogany, Gaboon	E
	Okoumé	E
Baikiaea plurijuga	"Teak, Rhodesian"	D
Beilschmiedia tawa	Tawa	E
Berlinia spp.	Berlinia	E
Betula alleghaniensis	Birch, Canadian yellow	G
	Birch, yellow	G
Betula papyrifera	Birch, paper	H
Betula verrucosa	Birch, European	F
Bombax insigne	Didu	K
Brachylaena hutchinsii	Muhuhu	B
Brachystegia spp.	Okwen	E
Brachystegia boehmii	Mjombo	C
Brachystegia spiciformis	Mtondo	C
Brya ebenus	Cocuswood	A
Burkea africana	Maccarati	B

See footnotes at end of table.

Table 14. --Index of British schedules for kiln drying lumber[1]--Continued

Timber		Schedule[2]
Botanical name	Commercial name	
Buxus macowanii	Box, Cape	B
	Boxwood, East London	B
Buxus sempervirens	Box	B
Byrsonima spicata	Serrette	E
Caesalpinia granadillo	Partridgewood	C
Calophyllum spp.	Bintangor	A
Calophyllum brasiliense	Jacareuba	A
Calophyllum brasiliense var. *rekoi*	Santa Maria	A
Calycophyllum candidissimum	Degame	B
Canarium euphyllum	Dhup	H
Canarium schweinfurthii	Canarium, African	H
Carapa guianensis	Andiroba	C
	Crabwood	C
Cardwellia sublimis	"Silky-oak, Australian"	E
Cariniana sp.	Jequitiba	D
Carpinus betulus	Hornbeam	E
Carya spp.	Pecan	E
Carya glabra	Hickory	E
Cassipourea malosana	Pillarwood	[4]A
Castanea sativa	Chestnut, sweet	D
Castanospermum australe	Black bean	C
Catostemma commune	Baromalli	E
Cedrela fissillis	"Cedar, South American"	H
Cedrela toona	"Cedar, Burma"	H
	Toon	H
Ceiba pentandra	Ceiba	J
Celtis spp.	Celtis, African	H
Celtis occidentalis	Hackberry	H
Centrolobium ochroxylon	Amarillo	E
Ceratopetalum apetalum	Coachwood	E
Chamaecyparis lawsoniana	"Cedar, Port Orford"	J
Chamaecyparis nootkatensis	"Cedar, yellow"	J
Chlorophora excelsa	Iroko	E
Chloroxylon swietenia	Satinwood, Ceylon	C
	Satinwood, East Indian	C
Chrysophyllum spp.	Longui rouge	E
Chrysophyllum albidum	White star apple	E
Chukrasia tubularis	Chickrassy	E
Combretodendron africanum	Essia	B

See footnotes at end of table.

Table 14.--Index of British schedules for kiln drying lumber [1]--Continued

Timber		Schedule [2]
Botanical name	Commercial name	
Cordia alliodora	Laurel, Ecuador	E
	Salmwood	E
Cordia goeldiana	Freijo	E
Cornus florida	Cornel	E
	Dogwood	E
Cratoxylon arborescens	Geronggang	E
Croton megalocarpus	Musine	C
Cylicodiscus gabunensis	Okan	B
Cynometra alexandri	Muhimbi	B
Dacrydium cupressinum	Rimu	K
Dacrydium elatum	Sempilor	K
Dacrydium franklinii	"Pine, huon"	K
Dalbergia latifolia	Rosewood, Indian	E
Dalbergia melanoxylon	Blackwood, African	B
Dalbergia stevensonii	Rosewood, Honduras	C
Daniellia ogea	Daniellia	J
	Ogea	J
Diospyros spp.	Ebony, African	E
Diospyros ebenum	Ebony, Ceylon	C
Diospyros virginiana	Persimmon	C
Dipterocarpus spp.	Apitong	D
	Bagac	D
	Gurjun	D
	Kanyin	D
	Keruing	D
	Yang	D
Dipterocarpus tuberculatus	Eng	D
Distemonanthus benthamianus	Ayan	F
Dryobalanops lanceolata	Kapur	H
Dumoria heckelii	Makoré	H
Dyera constulata	Jelutong	H
Endiandra palmerstonii	"Walnut, Australian"	E
	"Walnut, Queensland"	E
Entandrophragma angolense	Gedu nohor	A
Entandrophragma candollei	Omu	A
Entandrophragma cylindricum	Mahogany, Sapele	A
	Sapele	A
Entandrophragma utile	Mufumbi	A
	Sipo	A
	Utile	A

See footnotes at end of table.

Table 14.--Index of British schedules for kiln drying lumber[1]--Continued

Timber		Schedule[2]
Botanical name	Commercial name	
Eperua falcata	Wallaba	B
Erythrophleum guineense	Missanda	D
	Muave	D
	Tali	D
Erythroxylum mannii	Landa	E
Eucalyptus crebra	Ironbark	B
Eucalyptus diversicolor	Karri	C
Eucalyptus gigantea	"Oak, Tasmanian"	C
Eucalyptus globulus	Gum, blue	C
	Gum, southern blue	C
Eucalyptus maculata	Gum, spotted	C
Eucalyptus marginata	Jarrah	C
Eucalyptus microcorys	Tallowwood	C
Eucalyptus oblique	"Oak, Tasmanian"	C
Eucalyptus pilularis	Blackbutt	C
Eucalyptus regnans	"Oak, Tasmanian"	C
Eucalyptus saligna	Gum, saligna	C
Eucryphia cordifolia	Ulmo	C
Eusideroxylon zwageri	Belian	B
	Billian	B
Fagaropsis angolensis	Mafu	C
Fagus sylvatica	Beech, European	D
Flindersiana brayleyana	"Maple, Queensland"	C
Fraxinus spp.	Ash	D
Gonioma Kamassi	Kamassi	C
	"Boxwood, Knysna"	C
Gonystylus spp.	Melawis	C
	Ramin	[5]C
Gossweilerodendron balsamiferum	Agba	J
	Ntola	J
	Tola branca	J
	Tola white	J
Grevillea robusta	Grevillea	C
	"Silky-oak, African"	C
Guaiacum spp.	Lignum vitae	B
Guarea cedrata	Guarea	E
Guarea thompsonii	Guarea	E
Guarea excelsa	Cramantee	E
Guettarda sp.	Glassy wood	C

See footnotes at end of table.

Table 14.--Index of British schedules for kiln drying lumber[1]--Continued

Timber		Schedule[2]
Botanical name	Commercial name	
Hannoa klaineana	Fotie	L
Hopea odorata	Thingan	C
Hura crepitans	Assacu	E
	Hura	E
	Sandbox	E
Hymenaea courbaril	Courbaril	C
	Locust	C
Ilex aquifolium	Holly	C
Intsia bijuga	Merbau	C
Isoberlinia globiflora	Mchenga	C
Juglans cinerea	Butternut	E
Juglans nigra	Walnut, American	E
Juglans regia	Walnut, European	E
Juniperus procera	"Cedar, African pencil"	G
Khaya spp.	Mahogany, African	F
Koompassia malaccensis	Kempas	E
Larix decidua	Larch, European	H
Larix iaricina	Larch, tamarack	K
Larix leptolepis	Larch, Japanese	H
Larix occidentalis	Larch, western	K
Larix sibirica	Larch, Siberian	H
Laurelia aromatica	Laurel, Chilean	C
Liriodendron tulipifera	Whitewood, American	E
Lonchocarpus castilloi	Cabbage-bark, black	G
Lophira alata	Ekki	B
Lovoa klaineana	"Walnut, African"	E
Maesopsis eminii	Musizi	F
Magnolia spp.	Magnolia	E
Malus sylvestris	Apple	A
Mansonia altissima	Mansonia	H
Microberlinia brazzavillensis	Zebrano	B
Millettia stuhlmannii	Panga panga	E
Mitragyna ciliata	Abura	K
Mora excelsa	Mora	B
Mora gonggrijpii	Morabukea	B
Nesogordonia papaverifera	Danta	E
Newtonia buchanani	Muchenche	J

See footnotes at end of table.

Table 14.--Index of British schedules for kiln drying lumber [1]--Continued

Timber		Schedule [2]
Botanical name	Commercial name	
Nothofagus cunninghamii	"Myrtle, Tasmanian"	C
Nothofagus dombeyi	Coigue	B
Nothofagus menziesii	"Beech, silver"	E
	Beech, Southland	E
Nothofagus procera	Rauli	E
Nyssa aquatica	Gum, black	E
	Tupelo	E
Ochroma lagopus	Balsa	H
Ocotea spp.	Jigua	H
Ocotea rodiaei	Greenheart	B
Ocotea rubra	Determa	E
	Louro, red	E
Ocotea usambarensis	Camphorwood, East African	G
Octomeles sumatrana	Binuang	C
Olea hochstetteri	Olive, East African	E
Olea welwitschii	Loliondo	E
	Olive, Elgon	E
Palaquium spp.	Nyatoh	E
Parashorea spp.	Lauan	E
Parashorea malaanonan	"Seraya, white"	J
Paratecoma peroba	Peroba, white	D
Parinari excelsa	Mubura	B
Peltogyne spp.	Purpleheart	E
Pentace burmanica	Mahogany, Burma	E
	Thitka	E
Pentacme spp.	Lauan	E
Phoebe porosa	Imbuya	E
Picea abies	Spruce, European	K
	Whitewood (in part)	K
Picea engelmannii	Spruce, Engelmann	K
Picea glauca	Spruce, Eastern Canadian	K
	Spruce, white	K
Picea mariana	Spruce, black	K
Picea rubra	Spruce, red	K
Picea sitchensis	Spruce, Sitka	J
Pinus banksiana	Pine, jack	L
Pinus caribaea	Pine, British Honduras pitch	H
	Pine, Caribbean pitch	H
Pinus oocarpa	Pine, British Honduras pitch	H
	Pine, Caribbean pitch	H

See footnotes at end of table.

Table 14.--Index of British schedules for kiln drying lumber[1]--Continued

Timber		Schedule[2]
Botanical name	Commercial name	
Pinus contorta var. *latifolia*	Pine, lodgepole	L
Pinus echinata	Pine, shortleaf pitch	L
Pinus lambertiana	Pine, sugar	L
Pinus monticola	Pine, western white	L
Pinus nigra	Pine, Austrian	M
Pinus nigra var. *calabrica*	Pine, Corsican	M
Pinus palustris	Pine, American pitch	L
	Pine, longleaf pitch	L
Pinus pinaster	Pine, maritime	M
Pinus ponderosa	Pine, ponderosa	L
Pinus radiata	Pine, insignis	K
	Pine, radiata	K
Pinus resinosa	Pine, Canadian red	L
	Pine, red	L
Pinus strobus	Pine, yellow	L
	Pine, Weymouth	L
Pinus sylvestris	Pine, Scots	[3]M, F
	Redwood, European	M
Pinus taeda	Pine, loblolly pitch	L
Piptadenia macrocarpa	Curupay	G
Piptadeniastrum africanum	Dahoma	A
	Ekhimi	A
Platanus acerifolia	Plane, London	E
Plathymenia reticulata	Vinhatico	E
Podocarpus spp.	Podo	A
Podocarpus dacrydioides	"Pine, New Zealand white"	
Podocarpus guatemalensis	Yellowwood, British Honduras	H
Podocarpus nubigenus	Manio	J
Podocarpus spicatus	Matai	J
Podocarpus totara	Totara	J
Populus spp.	Poplar, black	E
	Cottonwood	H
Populus alba	Poplar, white	E
Populus balsamifera	Poplar, balsam	E
	Poplar, Canadian	E
Populus canescens	Poplar, grey	E
Populus tremula	Aspen, European	E
Populus tremuloides	Aspen, Canadian	E
Prioria copaifera	Cativo	C
Protium decandrum	Kurokai	C
Prunus avium	Cherry	A

See footnotes at end of table.

Table 14.--Index of British schedules for kiln drying lumber[1]--Continued

Timber		Schedule[2]
Botanical name	Commercial name	
Pseudotsuga menziesii	"Fir, Douglas"	K
Pterocarpus angolensis	Muninga	J
Pterocarpus dalbergioides	Padauk, Andaman	F
Pterocarpus macrocarpus	Padauk, Burma	F
	Pradoo	F
Pterocarpus soyauxii	Padauk, African	J
Pterygota kamerunensis	Pterygota	H
Pycnanthus angolensis	Akomu	C
	Ilomba	C
	Pycnanthus	C
Pygeum africanum	Mueri	C
Pyrus communis	Pear	A
Quercus spp.	Oak, American red	C
	Oak, American white	C
	Oak, Japanese	C
Quercus castaneaefolia	Oak, Persian	B
Quercus cerris	Oak, Turkey	B
Quercus robur	Oak, European	C
Ricinodendron rautanenii	Mugongo	K
Robinia pseudoacacia	Robinia	A
Salix spp.	Willow	H
Salix alba var. *coerulea*	Willow, cricket-bat	D
Sandoricum indicum	Katon	E
Sarcocephalus diderrichii	Opepe	E
Scottellia coriacea	Odoko	E
Sequoia sempervirens	Redwood, Californian	K
	Sequoia	K
Shorea spp.	Chan	D
	Lauan	E
	Meranti	E
	Seraya, red	F
Shorea faguetiana	Seraya, yellow	J
Sindora spp.	Sepetir	G
Sterculia oblonga	Okoko	C
	Sterculia, yellow	C
Sterculia pruriens	Maho	A
Sterculia rhinopetala	Sterculia, brown	B
Swartzia leiocalycina	Wamara	B

See footnotes at end of table.

Table 14.--Index of British schedules for kiln drying lumber[1]--Continued

Timber		Schedule[2]
Botanical name	Commercial name	
Swietenia macrophylla	Mahogany, Central American	F
Swietenia mahogoni	Mahogany, Cuban	F
Symphonia globulifera	Waika chewstick	C
Syncarpia glomulifera	Turpentine	C
Tabebuia sp.	Guayacan	E
Tabebuia spp.	Lapacho	E
Tabebuia pentaphylla	Mayflower	E
	Roble, Eucadorian	E
Tarrietia spp.	Mengkulang	D
Tarrietia cochinchinensis	Chumprak	C
Tarrietia utilis	Niangon	E
	Nyankom	E
Taxodium distichum	"Cypress, southern"	K
Taxus baccata	Yew	G
Tectona grandis	Teak	H
Terminalia spp.	"Laurel, Indian"	C
	Taukkyan	C
Terminalia amazonia	Nargusta	C
	Olivier, white	C
Terminalia bialata	Chuglam, white	E
	Silver, grey wood, Indian	E
Terminalia ivorensis	Afara, black	J
	Idigbo	J
Terminalia procera	Bombway, white	E
Terminalia superba	Afara	J
Tetramerista glabra	Punah	C
Thuja occidentalis	"Cedar, white"	J
Thuja plicata	"Cedar, western red"	J
Tilia americana	Basswood	K
Tilia vulgaris	Lime, European	H
Triplaris guayaquilensis	Fernan sanchez	E
Triplochiton scleroxylon	Obeche	L
	Wawa	L
Tristania conferta	Brush box	C
Tsuga canadensis	Hemlock, eastern	K
Tsuga heterophylla	Hemlock, western	L
Turraeanthus africanus	Avodiré	E
Ulmus spp.	Elm, Japanese	F
Ulmus americana	Elm, white	F

See footnotes at end of table.

Table 14. --Index of British schedules for kiln drying lumber[1]--Continued

Timber		Schedule[2]
Botanical name	Commercial name	
Ulmus glabra	Elm, wych	A
Ulmus hollandica var. *hollandica*	Elm, Dutch	A
Ulmus procera	Elm, English	A
Ulmus thomasii	Elm, rock	D
Virola koschnyi	Banak	C
Virola surinamensis	Badoen	C
	Dalli	C
Vochysia spp.	Quaruba	A
	Yemeri	A
Xylia dolabriformis	Pyinkado	C

[1] British Forest Products Research Laboratory Leaflet No. 42 (Appendix A).

[2] Relative humidity, 5 percent higher when thickness exceeds 1-1/2 inches, and 10 percent higher when it exceeds 2-1/2 inches.

[3] Use the second schedule if color of the wood is to be important.

[4] Relative humidities 10 percent higher when thickness exceeds 1-1/2 inches.

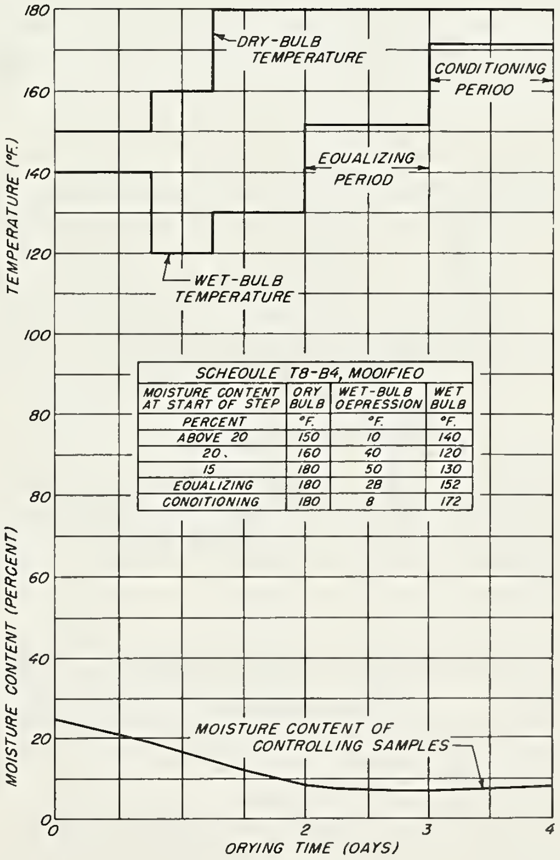
[5] Ramin that exceeds 1-1/2 inches in thickness should be dried in accordance with schedule D, using 5 or 10 percent higher relative humidity as required.

Kiln Schedule for Air-Dried Lumber

A simple schedule for kiln drying 1-inch lumber that has been carefully air dried to 25 percent moisture content or less is given in Table 15. A graph of the drying conditions and drying curve when a similar schedule is used on 1-inch black cherry in a small modern kiln is shown in Figure 67. Drying time to each change in drying conditions would be longer with lower temperatures and less modern kilns, but the changes can safely be made on the moisture content basis when the kiln sample method is used. This general schedule at the dry-bulb temperatures shown can be used for many easy-to-moderate drying softwoods and hardwoods, but different temperatures suggested by the final stages of Tables 9 through 13 may be better for other woods (Table 14). When starting the kiln for such drying, the vents should be closed. The steam spray of water spray should be shut off until the dry-bulb temperature is up to the schedule temperature. From then on the spray may be used sparingly as needed.

Table 15.--Kiln schedule for 1-inch hardwoods that have been air-dried to 25 percent moisture content or less

Moisture content at start of schedule step	Dry-bulb temperature	Wet-bulb temperature	Wet-bulb depression	Relative humidity
Percent	°F.	°F.	°F.	Percent
Above 20	140	130	10	75
20	150	120	30	41
15	160	120	40	31
Equalizing	160	144	16	65
Conditioning	170	165	5	89



SCHEDULE T8-B4, MODIFIED

MOISTURE CONTENT AT START OF STEP	DRY BULB	WET-BULB DEPRESSION	WET BULB
PERCENT	°F.	°F.	°F.
ABOVE 20	150	10	140
20	160	40	120
15	180	50	130
EQUALIZING	180	28	152
CONDITIONING	180	8	172

Figure 67.--American kiln drying schedule and drying curve for air-dried 1-inch black cherry lumber.

EQUALIZING AND CONDITIONING TREATMENTS

In the final stage of kiln drying, there is often considerable variation in the moisture content of individual boards. This is undesirable because it may cause trouble during storage, fabrication, or use. Furthermore, if the lumber is to be conditioned for the relief of drying stresses (often referred to as casehardening), a variation in moisture content will decrease the efficiency of the conditioning treatment. This variation in moisture content can be reduced by the use of an equalizing treatment.

A conditioning treatment is given primarily for the relief of drying stresses (casehardening). It also brings about a greater uniformity of moisture content among the outer and inner portions of the boards. Stress-free lumber is required where the lumber is to be resawed, ripped into thin strips, or machined differently on the two faces. Equalizing and conditioning treatments cannot be done correctly unless kiln samples are used.

Equalizing Treatment

The procedure for equalizing is:

(1) Start when the moisture content of the driest kiln sample is 2 percent below the desired final average moisture content. (For example, with a desired final average moisture content of 11 percent, the treatment would start when the driest kiln sample reaches 9 percent.)

(2) Establish a temperature and relative humidity within the kiln that corresponds to the moisture content of the driest sample. (In this example, to 9 percent.) Use as high a dry-bulb temperature as the drying schedule permits.

(3) Continue the equalizing treatment until the wettest sample reaches the desired final average moisture content. (In this example, 11 percent.)

Conditioning Treatment

The conditioning treatment can be started when the moisture content of the wettest sample equals the final desired average moisture content. The procedure for conditioning is:

(1) Maintain the kiln temperature at that of the final step of the schedule unless the required wet-bulb depression cannot be established at that temperature. If this is the case, lower the dry-bulb temperature to a suitable value about 12 hours before conditioning is to start.

(2) Establish a relative humidity that will result in a wood equilibrium moisture content about 4 percent above that of the desired final average moisture content. For example, if a hardwood is being dried to a final moisture content of 11 percent at a temperature of 170°F., then the wood EMC during

conditioning should be 15 percent. Table 2 indicates that at a temperature of 170°F. a wet-bulb depression of 5°F. will produce a relative humidity of 89 percent. This corresponds to a wood EMC of 15 percent. For a softwood being kiln dried under the same conditions, the wet-bulb depression during conditioning would be about 6°F. This would correspond to a wood equilibrium moisture content of 14 percent.

(3) The conditioning treatment should be continued until the stresses have been relieved. For 1-inch hardwoods the time may vary from 16 to 24 hours, and for 2 inch up to 48 hours. For 1-inch softwoods the time may be as short as 4 hours.

The equalizing and conditioning EMC values for other final moisture content values can be found from Table 2. It is very difficult to relieve stresses in stock above 11 percent moisture content.

Final Moisture and Stress Tests

When the material has been kiln dried, equalized, and conditioned, three 1-inch sections are cut from each kiln sample or 4 to 10 of the other boards in the kiln charge. These are for final tests of average moisture content, distribution of moisture between shell and core, and drying stress (casehardening). The sections should be cut at least 8 inches from the end of kiln samples and 20 inches or more from the end of boards. The details of cutting the moisture distribution and casehardening sections are shown in Figure 68.

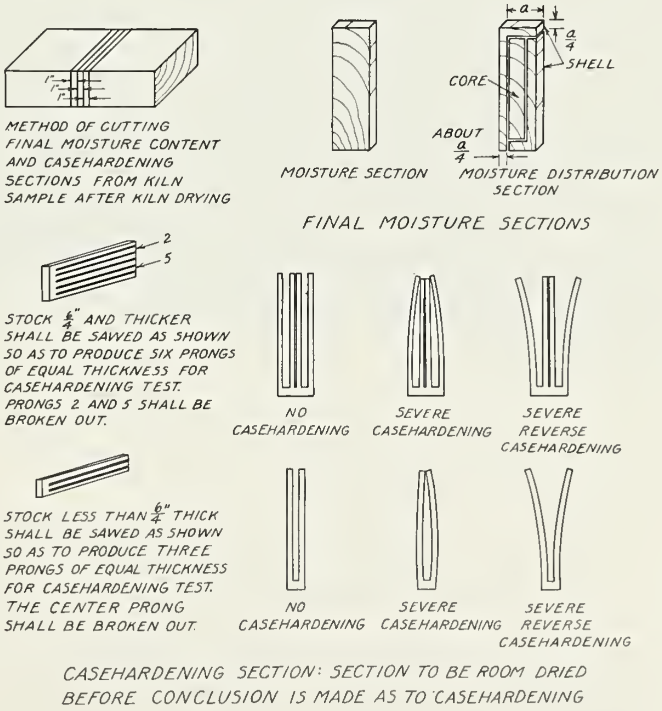


Figure 68.--Details for making and interpreting final moisture content and stress tests.

The reaction of the prongs at the time of sawing usually indicates the stress condition, but final conclusions cannot be drawn until the prongs have been air-dried for 24 hours.

When the operator thinks conditioning at the proper relative humidity has been long enough, he can shut the kiln off, remove some of the samples or other boards, and cut a stress test section from each. If, at the time of sawing, the outer prongs turn away from the saw (outward) about as much as the thickness of the prong or slightly more, the stock is usually free of casehardening and the lumber can be taken from the kiln. If the freshly cut prongs are straight or pinched in at the time of sawing, the stock is still casehardened. Conditioning at the proper temperature and relative humidity should be started again and continued at least 4 hours for 1-inch lumber or 8 hours for 2-inch stock before another stress test is made.

After the stress prongs have been room dried for 24 hours, or when the lumber has been cooled 24 hours before testing, one of the following results may be observed:

(1) The outer prongs have turned in considerably. This indicates the stock is still casehardened and the conditioning treatment on the next charge of the same material should be extended.

(2) The outer prongs are straight. The lumber is free of casehardening. Other charges of the same material should have the same conditioning time.

(3) The outer prongs have turned out considerably. The stock is reverse casehardened. The next charge of similar material should be conditioned at a lower relative humidity or for a shorter time.

DRYING RATE AND DRYING TIME

The drying rate of any lumber is strongly influenced by the temperature within the kiln. The higher the temperature, the more rapid the drying. Drying rate will also vary with the relative humidity within the kiln. The lower the relative humidity, the more rapid the drying. These two factors determine the time required to reach a certain moisture content. In drying North American woods, kiln time for green hardwoods 1-inch thick generally is between 6 and 30 days. Green 1-inch softwoods generally take 2 to 20 days. Air-dried 1-inch hardwoods generally take 3 to 12 days in the kiln, and air-dried softwoods take somewhat less time.

KILN DRYING DEFECTS

The information on drying defects presented under "Air Drying" also applies generally to defects that develop during kiln drying. Certain defects, however, are peculiar to kiln drying or develop to a greater extent during kiln drying; so they are discussed here.

Defects Associated with Shrinkage

Kiln-dried lumber is generally reduced to a low moisture content; so kiln drying is likely to magnify any defect that results from shrinkage. Where a suitable kiln schedule is used, however, defects can be limited or prevented.

Collapse.--Collapse results in an excessive amount of shrinkage caused by the buckling of the cell walls. There is a considerably greater than normal decrease in overall dimensions. More severe collapse can occur in some zones that in others, resulting in a "washboard" effect. The wood of certain species is very susceptible to collapse. Figure 69 shows severe collapse in a wood of high moisture content and thin cell walls. Very wet heartwood of balsa also will collapse severely. Eucalyptus, which has thicker but impervious cell walls, also collapses severely. While most woods do not collapse severely and many do not collapse at all, a small degree of collapse can be troublesome in some cases.

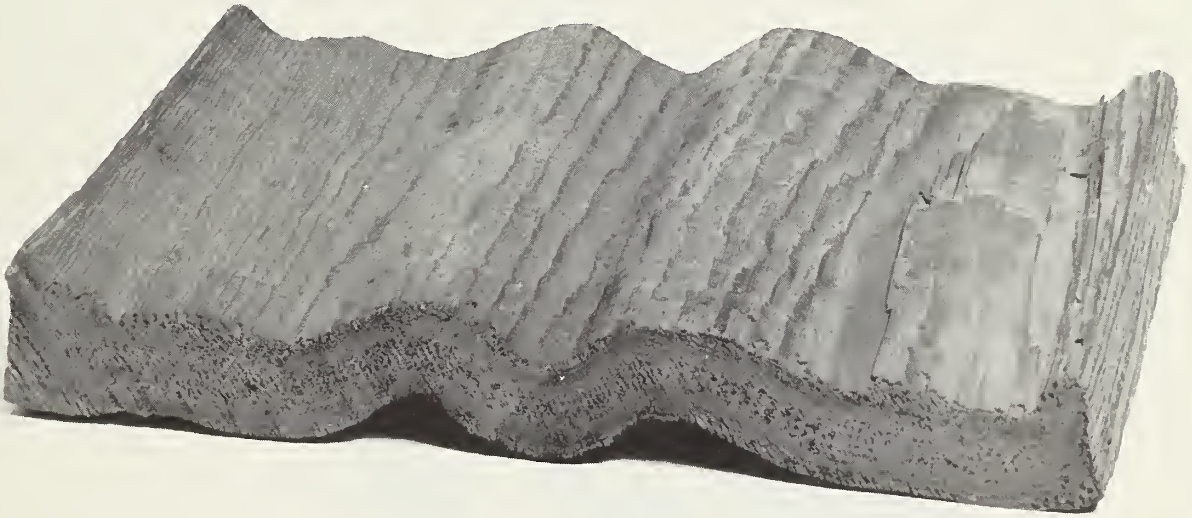


Figure 69.--Severe collapse in western red cedar.

Collapse is likely to occur when high kiln temperatures are used during the early and intermediate stages of drying green wood. If collapse develops when a moderate kiln schedule is used, try a lower temperature schedule. If this still causes collapse, the stock should be air dried to about 20 percent moisture content before kiln drying is started. In Australia, many operators prefer to air dry or predry the green material and get a moderate amount of collapse, then use a "steaming" treatment to "recondition." This is done prior to kiln drying. Such procedures are beyond the scope of this present publication.

Honeycombing.--Honeycombing is more common and more severe in kiln drying than in air drying. Honeycombing occurs during the late stages of kiln drying, but it is related to things that have happened during the earlier stages. It is more likely to occur when high kiln temperatures are used. Honeycomb checks often are interior enlargements of surface checks or end checks that have closed on the surface. Honeycomb checks generally cannot be detected until the piece is sawed or dressed (Figure 42). Sometimes, however, their presence is indicated by grooves on the surface.

High kiln temperatures should be avoided from the start of drying until the interior parts of the wood are below the fiber saturation point to avoid honeycomb checking.

Drying stresses or casehardening.--Any drying process, whether air drying, predrying, or kiln drying, results in a stressed condition at the end of the process. This stressed condition is called casehardening. It is usually mild under air drying or predrying, but may be severe under kiln drying. In casehardened lumber the surface layers are in compression while the interior is in tension. Casehardening interferes with the efficient use of the lumber for certain products. Figure 70 illustrates the distortions in shape when casehardened lumber is resawed or machined unevenly. Fortunately, casehardening can be relieved by conditioning as discussed under the heading "Equalizing and Conditioning Treatments."

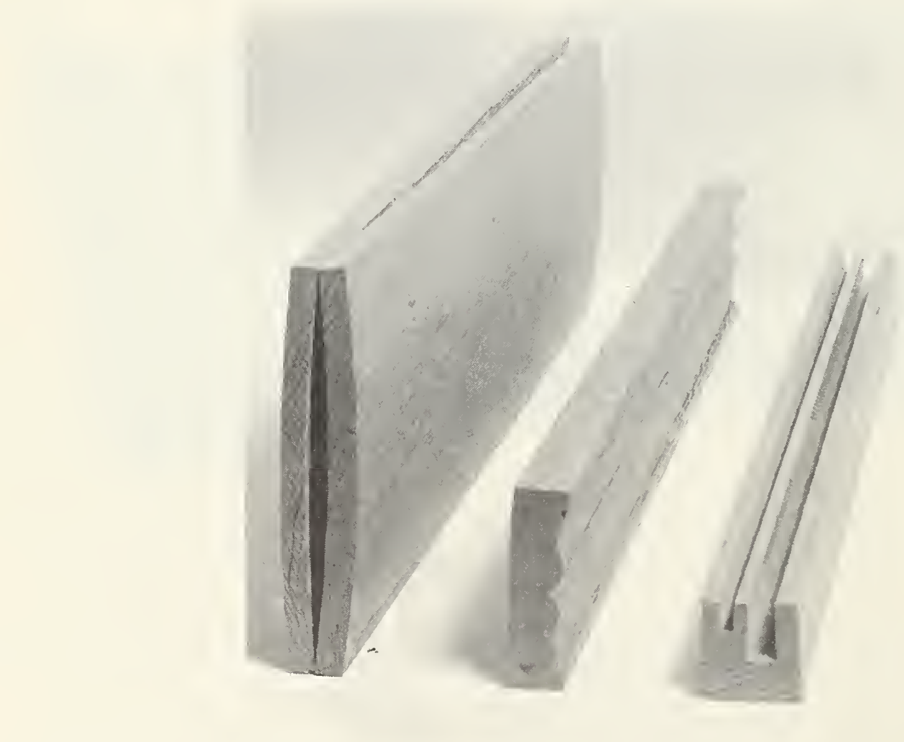


Figure 70.--Distortion caused by casehardening in stock resawed (left), machined heavily on one face (center), or deeply grooved (right).

Reverse casehardening can occur if too high a relative humidity is used during conditioning. The surface layers then are in tension and the interior in compression. Wood with reverse casehardening distorts in the direction opposite to casehardened lumber. No satisfactory method of relieving reverse casehardening has been established.

Defects Caused by Chemical Reaction

Color changes caused by chemical actions can occur in wood during kiln drying. These discolorations are usually worse when high temperatures and high relative humidities are used. There may be sticker marks across the faces of the boards. In some cases, the wood under the stickers is light with the rest of the wood being dark. In other cases, the sticker mark is dark. Another type of discoloration that appears chiefly during kiln drying of soft pines or similar softwoods is brown stain. Brown stain may appear on the surfaces or in zones slightly below the surfaces. There are other changes in color that appear during kiln drying; for example, the "pinking" in hickory. Lumber sawed from old logs appears to be more likely to discolor than lumber sawed from fresh logs. In general, low humidity drying at low-to-moderate temperatures tends to keep chemical stain at a minimum. Enzyme-inhibiting treatments such as preliminary steaming or special chemical dips may be needed for some stains.

Defects Caused by Fungi

Sap stain and decay do not ordinarily occur in lumber that is being kiln dried. However, when a kiln is operated at a low temperature and the circulation of air within the kiln is not adequate and uniformly distributed, the conditions in certain cold spots in the kiln may be favorable to the development of mold and sap stain fungi. In some cases, the mold may develop to such an extent that it will completely block the passages between the courses of lumber, thus shutting off the circulation of air through the lumber pile at this point. Steaming at saturation and 130°F. for 1 hour after the kiln reaches this condition generally will kill the mold.

SAFETY PRECAUTIONS FOR DRY KILNS

Careful Operations

Kiln drying normally is not hazardous, but carelessness may lead to serious or even fatal injury. The following safety rules should be followed:

(1) Shut off heat, spray, and fans before going in a kiln. Cool the kiln somewhat if it has been very hot. No one should go in a kiln until the wet-bulb temperature has cooled down below 120°F. No one in poor health should go in a kiln at temperatures over 100°F.

(2) When entering a kiln that has been operating, someone nearby should be notified to render assistance if necessary. The door should be fastened open and a sign hung on it reading "Man Inside Kiln, Do Not Close Door."

(3) Kiln door latches should open from both inside and outside. Never use props to hold a door closed. Someone may be inside.

(4) Do not allow anyone to go in an operating kiln to warm himself or get shelter.

(5) Use extreme care in opening and closing large kiln doors. Heavy doors need two or more men to operate. Keep door equipment in good repair.

(6) The walkways over track-level openings in natural circulation kilns should be of strong open-type construction, inspected frequently, and kept in good repair. The baffles and their supporting framework should be strong, well painted, and kept free of oil or corrosion. Shafts and pulleys should have guards.

(7) If kiln fans are to be inspected or lubricated, the fan switch should be locked in the "off" position, or a sign should be placed on the switchbox, "Do Not Start Fans. Man Working."

(8) When entering a kiln, always use a flashlight. Never use an open flame for a light. Be on guard against falling or protruding objects, also against touching hot metal or slipping on oil.

(9) When men are used to move loaded kiln trucks, enough men should be used. They should have good footing and use care not to crush anyone against the walls or between the loads. Cable-operated loading devices should be inspected often and worn cables discarded. Stay clear of the cable when it is operating.

(10) The dry kiln and the area around it should be kept free of debris.

Prevention of Fires in Dry Kilns

Fires are not common in modern kilns. They are a constant danger in the hot-air kiln and may occur through some unsafe practice in other kilns. Suggestions to avoid fires in kilns are:

(1) Install all heat-protecting features included in the kiln design.

(2) Never operate a kiln at temperatures higher than it can stand.

(3) Use metallic steam pipe supports and use mineral insulation where steam pipes go through or come near wood. It is suspected that kiln fires in steam-heated kilns have started where steam pipes have been in actual contact with wood for a long time.

(4) Keep electrical wiring and switches dry and in good condition.

(5) Keep all motor, fan, and shaft bearings well lubricated.

(6) Never allow anyone to smoke in or around a kiln.

(7) When using a welding or cutting torch, keep away from any flammable liquid or vapor. Have a fire extinguisher nearby.

Control of Kiln Fires

The following will stop or reduce the spread of fires:

(1) High-cost kilns should have automatic sprinkler systems installed as part of the original equipment. When a fire starts in such a kiln, the sprinkler puts it out immediately.

(2) In a hot-air kiln, pull out as much fuel as possible and throw dirt or water on the rest of the fire. Then close the damper and draft control. Put dirt in all openings around the bottom of the kiln and keep the front panels closed. Throw water on any of the outside of the kiln that starts to smoke or burn.

(3) In other kilns, keep all doors closed. Close all ventilators and fresh air inlet doors.

(4) Shut off fans in forced circulation kilns.

(5) If the kiln has a steam or water spray, turn it on full force by opening the hand valve, bypassing any automatic control valve if possible, or by setting the wet-bulb indicator on the automatic instrument up to the top setting.

A sign telling the fire control measures for the kiln in question should be posted on each kiln.

STORAGE OF DRY LUMBER

Lumber that has been dried to a moisture content suitable for use or for shipment should be protected from the weather. If it is necessary to store lumber regularly for any considerable period, substantial storage sheds or rooms should be provided. Lumber that has been air dried or predried needs protection against rain and other forms of precipitation or damp or wet ground. Lumber that has been reduced to a low moisture content level needs protection from atmospheric water vapor as well. Efficient protection against moisture will maintain the lumber at its moisture content level and probably bring about a greater uniformity of moisture content.

Proper storage also helps avoid deterioration from other sources. If the moisture content is maintained at a value below 20 percent, there is no risk of deterioration from blue stain or decay. Certain insects, however, do attack relatively dry wood, and special precautions are needed where wood-destroying insects are a problem.

TYPES AND METHODS OF STORAGE

Outdoor Storage

Outdoor storage may be used for partially or fully air-dried or predried material. Lumber at a moisture content above 20 percent may be stored outdoors in piles like those in an air-drying yard. Lumber that is below 20 percent, but still wetter than is suitable for its intended use, should have the same treatment. If lumber is at a moisture content of below 20 percent and it is not necessary to reduce it to a lower figure, the lumber may be stored outdoors in solid piles. Both types of piles should be protected from the weather. The piles should be roofed as in air drying. Solid piles also should be protected around the sides from wind-blown rain or snow. Moisture that penetrates solid piles is not readily removed by evaporation.

Open Sheds

Lumber stored in open sheds (Figure 71) is exposed to the same atmospheric conditions as that stored outdoors. Therefore, such storage is only suitable for air-dried or predried lumber. The roof of the sheds, if it has sufficient overhang, affords far better protection against wetting and sunshine than roofs on outdoor piles. If the moisture content of the lumber is above 20 percent, then the lumber should be piled on stickers; if the moisture content is below 20 percent and no further drying is desired, the lumber can be stored in solid piles. In either case, the lumber should be supported some distance above the ground by timbers or a strong lattice floor.

Figure 71.--Open storage shed for construction lumber.

Closed Sheds

Closed sheds (Figure 72) are generally used to store lumber that has been dried to a lower moisture content level by prolonged air drying or pre-drying or by kiln drying. An unheated closed shed should have controlled vents in the roof and in the walls. The closing of the vents in damp weather and opening them in dry weather affords some measure of control of the atmosphere within the sheds. The area on which the shed stands should be relatively high and well drained so that the floor remains dry. By proper operation of the vents, if may be possible to hold lumber within a closed shed at a moisture content somewhat lower than that of lumber stored outdoors.

Heated Sheds

Lumber or other wood items that have been kiln dried to a very low moisture content should be stored in a heated shed. Heating the air within a shed causes it to assume a lower relative humidity than the air outdoors. If no moisture vapor is added to the air within the sheds, a small amount of heating will result in a low relative humidity which will maintain lumber at a low moisture content (Figure 73). The following example illustrates the use of this Figure. If air at a temperature of 30°F. and 75 percent relative humidity is heated to 45°F., the relative humidity will be about 41 percent.

Figure 72. --Closed portion of a storage shed for lumber dried to a low moisture content.

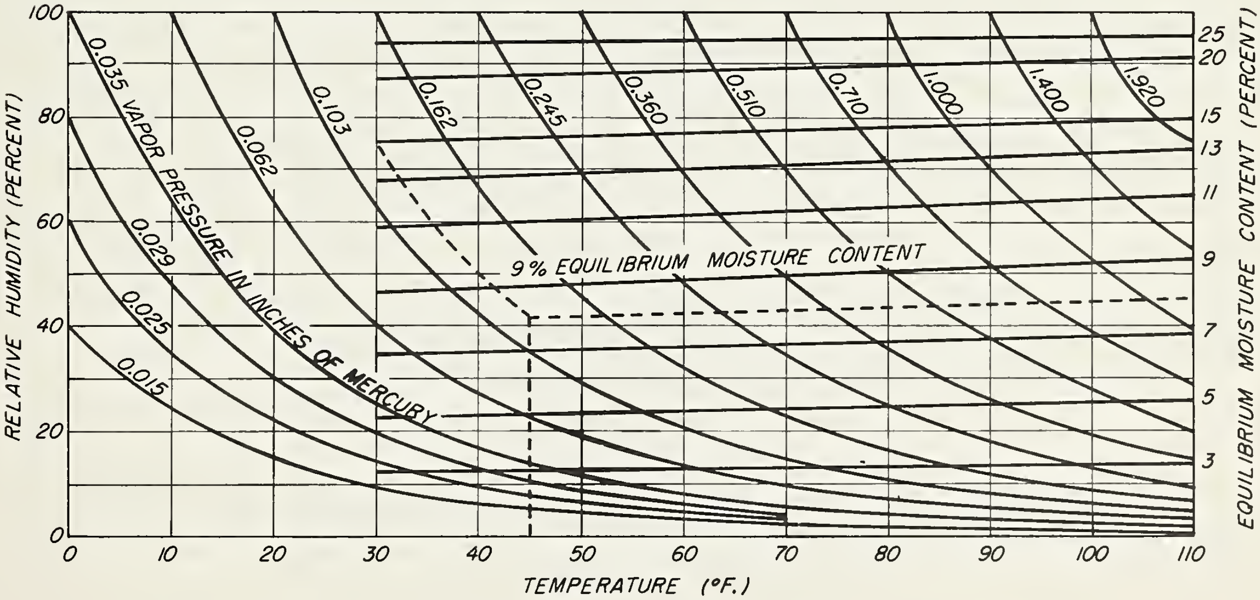


Figure 73. --Chart showing water vapor pressure and wood equilibrium moisture content for different dry-bulb temperatures and relative humidities.

This corresponds to a wood equilibrium moisture content of about 8 percent. This result is obtained by following the dashed lines on the chart.

The shed can be heated by various methods, including steam or hot water coils, space heaters, or solar energy. A relatively small amount of heat is needed, but it is necessary to circulate the heated air so that it reaches all parts of the shed. If some means of circulating the air are not provided, the hot air will rise to the top of the shed and stay there.

APPENDIX A

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APPENDIX B

Equipment, Manpower, and Relative Costs for Air Drying, Predrying, and Kiln Drying in the United States

The costs given below are general estimates only, using American material and labor costs. They are generally on the basis of a thousand board feet (M bd. ft.). Individual costs would differ considerably from these in other countries.

General Manpower Requirements

Grading and stacking lumber for drying at a:

Small mill (4 to 8 M bd. ft. daily)	1-2 men
Larger mill (10 to 20 M bd. ft. daily)	2-4 men
Transporting lumber (at small mill, will assist in piling)	1 man

Stacking, Unstacking, Transportation Costs

Stacking per M bd. ft.	$1.00 to $2.00
Unstacking per M bd. ft.	.50 to 1.00
Transportation per M bd. ft.	.40 to .50

Air Drying

Grading, surfacing yard, foundations, stickers, roofs, yard rent, interest on equipment and on value of lumber drying, fire protection, insurance, and supervision.

Estimated cost per day per M bd. ft. $0.05 to $0.10

(For example, an item of 1-inch hardwood lumber that takes 60 days to air dry to 20 percent moisture content at $0.10 per day would cost $6.00 + $1.00 (stacking) + $0.50 (unstacking) + $0.50 (transportation) or a total of $8.00 per M bd. ft.)

Estimated additional cost of air drying to 15 percent moisture content under favorable drying conditions per M bd. ft. $2.50

Predrying Costs

First cost of building and equipment per M bd. ft. $100.00

(Labor costs are slightly higher than for air drying because of need to load and unload dryer rapidly. Supervision costs higher than air drying because of need to keep fans and operating equipment in good condition.)

Estimated cost of interest on building, stickers, foundations, fans and motors and value of lumber drying, fire protection, insurance, direct power costs, and supervision per day per M bd. ft. $0.20

(For example, assuming 1-inch lumber of a certain species will predry to 20 percent moisture content in 26 days, the cost would be $5.20 + $1.25 (stacking) + $0.75 (unstacking) + $0.40 (transportation) or a total of $7.60.)

Estimated additional cost for predrying to 15 percent moisture content under favorable air-temperature conditions per M bd. ft.	$2.00

Kiln Drying Costs

First cost of various kilns	Per M bd. ft.
Small hot air kiln (except lumber)	$85.00
Small natural circulation kiln (except boiler)	$750.00
Small internal-fan furnace kiln	$1,000.00
Modern steam-heated, internal-fan, automatically controlled kiln, wood construction, 5 to 8 years expected life	$1,250.00
Same, masonry construction, 15 to 30 years expected life	$2,000.00
Same, prefabricated panel type	$2,250.00
Small low-pressure boiler (1-1/2 to 2 boiler horsepower per M bd. ft.)	$350.00

Labor costs are somewhat higher than for predrying because of greater need to use kiln efficiently and move heavy loads of green lumber. Better maintenance (semi-skilled labor) needed to keep equipment in operating condition. Fireman for 1 to 5 hot-air kilns or boiler. Boiler engineer on duty at all times (or automatic boiler feed).

Trained kiln operator needed. For 1 to 3 kilns he can also carry maintenance or supervisory duties. Over 5 kilns an assistant operator is needed.

Supervision in addition to kiln operator needed if more than 3 kilns are involved.

Estimated cost of interest on building, equipment and value of lumber, fire protection, insurance, direct power costs, fuel, trained operator, maintenance, and supervision.

Per day per M bd. ft.:	for softwoods	$1.00
	for hardwoods	$2.00

(For example, a 1-inch hardwood taking 16 days to kiln dry from the green condition to 12 percent moisture content would cost $32.00 + $1.75 (stacking) + $0.75 (unstacking) + $0.50 (transportation) or a total of $35.00.)

Storage Shed Costs

Open pole-type shed costs $0.75 to $1.75 per square foot of floor area. Closed sheds $1.50 to $3.00. Heated closed storage costs $3.00 to $4.00. Cost per M bd. ft. would depend upon height to which lumber is piled.

Auxiliary Equipment

Moisture section balance	$ 25 to $135
Sample scales	$ 25 to $100
Oven, electric	$ 85 to $225
Thermometers	$ 2 to $ 5
Moisture meters	$100 to $200

APPENDIX C

Partial List of United States Suppliers of End Coatings for Logs and Lumber[1]

Akron Paint and Varnish Co., Akron 1, Ohio
Angier Products, Inc., 120 Potter St., Cambridge, Mass.

Barrett Div., Allied Chemical and Dye Corp., 40 Rector St., New York 6, N. Y.

Chapman Chemical Co., P.O. Box 138, Memphis 1, Tenn.
Cities Service Oil Co., 70 Pine St., New York, N. Y.

E. I. duPont de Nemours and Co., Finishes Division, Wilmington, Del.

The Flintkote Co., Industrial Products Div., 17th and Wentworth Ave., Chicago Heights, Ill.
W. P. Fuller and Co., 301 Mission St., San Francisco, Calif.

General Industrial Chemicals, 3048 Michigan Dr., Louisville 12, Ky.
General Paint Corp., 2nd and Taylor, Portland 7, Oreg.
General Petroleum Corp., 612 S. Flower, Los Angeles, Calif.
Gilbreath Chemical Co., 383 Brannon St., San Francisco, Calif.

Koppers Company, Tar Porducts Div., Koppers Bldg., Pittsburgh, Pa.

Lion Oil Company, El Dorado, Ark.
Longview Paint and Varnish Co., 1203 California Way, Longview, Wash.

Mautz Paint and Varnish Co., 933 E. Washington Ave., Madison 3, Wis.
Moore Dry Kiln Co., Jacksonville 1, Fla., or North Portland, Oreg.

Ohmlac Paint and Refining Co., 6550 S. Central Ave., Chicago, Ill.

Pittsburgh Plate Glass Co., 235 E. Pittsburgh Ave., Milwaukee 1, Wis.

Reilly Tar and Chemical Corp., 1615 Merchants Bank Bldg., Indianapolis 4, Ind.

Schorn Paint Mfg. Co., 1128-32 W. Spokane St., Seattle 4, Wash.
Sloss-Sheffield Steel and Iron Co., Birmingham 2, Ala.
Socony Mobil Oil Co., Inc., 26 Broadway, New York, N. Y.

R. T. Vanderbilt Co., 230 Park Ave., New York 17, N. Y.

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[1] Inclusion of names of companies implies no recommendation or endorsement of their products by the United States Government.

APPENDIX D

Partial List of United States Suppliers of Toxic Chemicals[1]

The following firms are known to be able to supply the materials shown. Possibly most firms on the list for item 1 can supply the other chemicals also.

1. Water-Soluble Chemicals for Spraying Logs or Dipping Green Lumber to Avoid Mold and Sap Stain

Borax Cons., Ltd., 630 Shatto Place, Los Angeles, Calif. (Borax)
Chapman Chemical Co., 714 Dermon Bldg., Memphis, Tenn. (Permatox)
Dow Chemical Co., 1000 Main St., Midland, Mich. (Dowicide)
E. I. duPont de Nemours and Co., Grasseli Chemicals Dept., Wilmington, Del. (Melsan, Lignasan)
Monsanto Chemical Co., Lindbergh and Olive St., St. Louis 24, Mo. (Santobrite)
Wood Treating Chemicals Co., 5137 Southwest Ave., St. Louis 10, Mo. (Noxtane)
R. T. Vanderbilt Co., Inc., 230 Park Ave., New York 17, N. Y. (Diprite)
Timber Products Chemical Co., Minneapolis, Minn. (Timber San)

2. Oil-Soluble Chemicals for Reduction of Stain and Decay in Logs

Chapman Chemical Co., 714 Dermon Bldg., Memphis, Tenn. (Permatox)
Dow Chemical Co., 1000 Main St., Midland, Mich. (Dowicide)
Monsanto Chemical Co., Lindbergh and Olive St., St. Louis 24, Mo. (Pentachlorophenol)
Wood Treating Chemicals Co., 5137 Southwest Ave., St. Louis 10, Mo. (Pentachlorophenol)

3. Oil- or Water-Soluble Benzene Hexachloride Emulsion for Log Spray or Lumber Dip to Avoid Insect Attack

California Spray Chemical Corp., Richmond, Calif.
Chapman Chemical Co., 714 Dermon Bldg., Memphis, Tenn.
Niagara Sprayer and Chemical Div., Food Machinery Corp., Middleport, N. Y.
South Atlantic Chemical Co., Charleston, S. C.
Thompson-Hayward Chemical Co., 2915 Southwest Blvd., Kansas City, Mo.
Wood Treating Chemicals Co., 5137 Southwest Ave., St. Louis 10, Mo.

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[1] Inclusion of names of companies implies no recommendation or endorsement of their products by the United States Government.

APPENDIX E

Partial List of United States Dry-Kiln Companies or Engineers and Accessory Suppliers[1]

Dry Kiln Companies

Fryer Dry Kiln Co. (Medford Machinery Co.), 6621 N. St. Louis, Portland 3, Oreg.
Imrie Dry Kiln Co., Michigan Trust Bldg., Grand Rapids 2, Mich.
C. M. Lovsted and Co., Inc., 4000 West Marginal Way, Seattle 6, Wash.
Moore Dry Kiln Co., P. O. Box 4248, Jacksonville 1, Fla., or North Portland, Oreg.
The National Engineering Co., 5775 Hillside Ave., Indianapolis 20, Ind.
H. L. Russell Dry Kiln Co., P. O. Box 124, Fordyce, Ark.
Standard Dry Kiln Co., P. O. Box 5708, Indianapolis 21, Ind.
Wel-Dri Company, 730 S. Third St., Memphis 2, Tenn.
Wilson Dry Kiln Co., P. O. Box 108, Olympia, Wash.

Accessory Suppliers

The Kiln Supply and Manufacturing Co., 5825 Oak Ave., Indianapolis 19, Ind.
Universal Door Carrier, Inc., 1117 Cornell Ave., Indianapolis 2, Ind.

Apparatus for Determining Moisture Content by Ovendrying

Central Scientific Co., 1702 Irving Park Road, Chicago 13, Ill.
Eimer and Amend, Div. of Fisher Scientific Co., 633 Greenwich St., New York 14, N. Y.
Fisher Scientific Co., 203 Fisher Bldg., Pittsburgh 19, Pa.
Palo Laboratory Supplies, Inc., 83 Reade, New York, N. Y.
Precision Scientific Co., 3737 Cortland, Chicago, Ill.
E. H. Sargent and Co., 4647 W. Foster Ave., Chicago 30, Ill.
Schaar and Co., 7300 W. Montrose, Chicago, Ill.
Arthur H. Thomas Co., Vine St. at Third, Philadelphia 5, Pa.
Will Corporation, Wilco Drive, Rochester 3, N. Y.

Electric Moisture Meters

Delmhorst Instrument Co., 117 Cornelia St., Boonton, N. J.
Kel Engineering and Equipment Co., P. O. Box 744, New Brunswick, N. J.
Moisture Register, 1510 W. Chestnut St., Alhambra, Calif.
Western Electrical Instrument Corp., Newark, N. J.

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[1] Inclusion of names of companies implies no recommendation or endorsement of their products by the United States Government.

APPENDIX F

Suggested Bill of Material for Small Hot-Air Kiln

Heater.--Iron firebox one-fourth inch thick, 2 feet in diameter, 18 feet long; 30 feet of 12-inch stove pipe, two angled elbows (45° adjustable), a damper, and a flue collar. A sheet of tin 24 by 24 inches. A spark arrester of 1/8 inch mesh screen. Twenty-six feet of 1-1/2 inch pipe and one T-connector.

Fire safeguards.--Thirty-four stones or concrete blocks 8 by 8 by 16 inches. A piece of tin 18 by 36 inches, one 24 by 24 inches, and eight pieces 20 by 20 inches. Twelve sheets of corrugated iron approximately 36 inches by 8 feet each. Eight pieces of asbestos paper, each 20 by 20 inches.

Foundations.--Eight sills 2 by 12 inches by 6 feet, made of the heartwood of a decay-resistant species. Forty-eight 8- by 8- by 8-inch stones or concrete blocks. Eight crossbeams or caps 7 by 9 inches by 6 feet.

Walls.--Six sills of durable heartwood, three to be 2 by 6 inches by 18 feet, two to be 2 by 6 inches by 7 feet, and one to be 4 by 4 inches by 4 feet 4 inches. Five sill caps, three to be 2 by 4 inches by 18 feet and two to be 2 by 4 inches by 7 feet. Twenty-one studs, sixteen to be 2 by 4 inches by 13 feet, three to be 2 by 4 inches by 4 feet, and two to be 4 by 4 inches by 9 feet. Two joists for over front doors, 4 by 4 inches by 6 feet 8 inches. Two rafters 4 by 6 inches by 18 feet. One-inch sheathing, all widths, as follows: 1,430 board feet, 18-foot lengths for two sides and back walls; 210 board feet, 13-foot 6-inch lengths vertically, in doors; 80 board feet, 4-foot lengths horizontally, in built-in front panels; 216 board feet, 7-foot 6-inch lengths horizontally, in doors; 325 board feet, 17-foot 6-inch roofing. Lumber to be air dried if possible.

Miscellaneous.--625 square feet tar paper. Sawdust. 5,000 stickers 1-1/2 inches by 1 inch by 6-1/2 feet. Wire. Nails. Two iron pipes each 2 inches in diameter, 13 feet long. Four pipes 1 inch in diameter, 13 feet long.

APPENDIX G

Exact Method of Calculating Shrinkage or Swelling of Wood With Change in Moisture Content

Tables 3, 4, and 5 give shrinkage values of wood dried to 0 percent moisture content, based on its dimensions when green. The values are given in terms of percent of green dimension. These values can be converted into dimensional changes, in inches or metric units, by using the following formula:

$$S = \frac{(M_I - M_F)\,D}{\left(\frac{30}{S_T \text{ or } S_R} - 30\right) + M_I}$$

Where S = shrinkage or swelling in inches or metric units
M_I = initial moisture content in percentage (maximum is 30)
M_F = final moisture content in percentage (maximum is 30)
D = dimension at initial moisture content in inches or metric units
30 = fiber saturation point in percentage
S_T = total tangential shrinkage, in percentage, divided by 100
S_R = total radial shrinkage, in percentage, divided by 100

Neither the initial nor the final moisture content (M_I or M_F) can be greater than 30 percent because that is the moisture content at which drying wood starts to shrink or swelling wood reaches its maximum dimension.

Example No. 1

Determine the shrinkage in width of a flat-grained Douglas-fir (*Pseudosuga menziesii*) board dressed to a width of 6-1/2 inches in drying from 20 to 6 percent moisture content.

$$S = \frac{(20 - 6)\,6.5}{\left(\frac{30}{0.078} - 30\right) + 20} = \frac{91}{374.6} = 0.243 \text{ inch}$$

From Table 3 the total tangential shrinkage of Doublas-fir (*Pseudosuga menziesii*, coast-type) is found to be 7.8 percent, which, divided by 100, gives an S_T of 0.078.

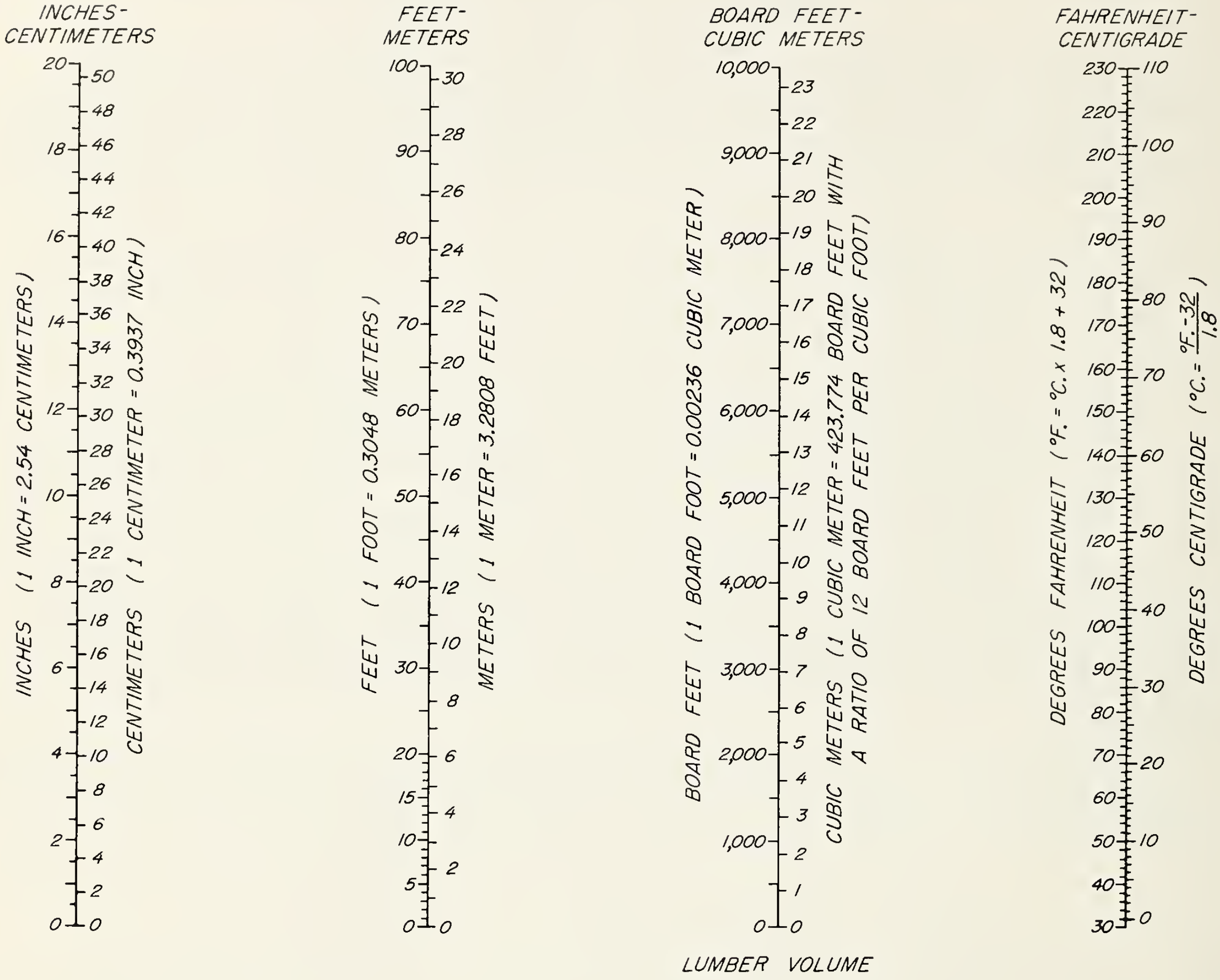
Example No. 2

Determine the swelling in width of a flat-grained sugar maple (*Acer saccharum*) flooring strip machined to 2-1/4 inches in changing from 5 to 13 percent moisture content.

$$S = \frac{(5 - 13)\,2.25}{\left(\frac{30}{0.095} - 30\right) + 5} = \frac{-18.0}{290.8} = -0.062 \text{ inch}$$

The negative value obtained in this problem denotes swelling, which is to be expected because the final moisture content was higher than the initial.

APPENDIX H



Scales for converting from some commonly used English units of measurement to metric units.

APPENDIX I

Centigrade Tables

Copies of Tables 2, 8, 9, 10, 11, 12, and 13 as expressed in ^{o}C. (If it is desired, these tables can be used to replace the same-numbered tables now in the text, but expressed in ^{o}F.)

Table 2. --Relative humidity and equilibrium moisture content of North American woods for various dry-bulb temperatures and wet-bulb depressions[1]

Dry-bulb temperature		Wet-bulb depression (°C.)																				
		1	1½	2	2½	3	3½	4	4½	5	6	7	8	9	10	12	14	16	18	20	22	25	28
°C.																							
5	R.H.	86	79	72	65	58	52	45	39	33	20	7	----	----	----	----	----	----	----	----	----	----	----
	EMC	19	16	14	12	11	9½	8½	7½	6½	4½	1½	----	----	----	----	----	----	----	----	----	----	----
15	R.H.	90	85	80	75	71	66	61	57	53	44	36	27	20	13	----	----	----	----	----	----	----	----
	EMC	20½	18	16	14½	13	12	11	10½	10	8	7	6	4½	3	----	----	----	----	----	----	----	----
25	R.H.	92	88	84	81	77	74	70	67	63	57	50	44	39	33	22	12	----	----	----	----	----	----
	EMC	21½	19½	17½	16	15	14	13	12	11½	10	9	8	7½	6½	5	2½	----	----	----	----	----	----
35	R.H.	94	90	87	84	81	78	75	72	69	64	59	54	49	44	36	28	20	13	7	----	----	----
	EMC	22	19½	18	16½	15½	14½	13½	13	12	11	10	9½	8½	8	6½	6	4	3	1½	----	----	----
40	R.H.	94	91	88	85	82	80	77	74	72	67	62	57	53	48	40	33	26	20	14	6	----	----
	EMC	22	19½	18	17	16	15	14	13	12½	11½	10½	9½	9	8	7	6	5	4	3	1½	----	----
45	R.H.	94	91	88	85	83	80	78	75	73	69	64	60	56	52	44	37	30	25	19	14	----	----
	EMC	22	19½	18	17	15½	15	14	13½	12½	11½	10½	10	9	8	7	6½	5½	4½	4	3	----	----
50	R.H.	95	92	89	86	83	81	79	76	74	70	65	61	58	54	46	40	34	29	24	18	12	5
	EMC	22	19½	18	16½	15½	15	14	13½	12½	11½	10½	10	9	8½	7½	6½	5½	5	4	3½	2½	1
55	R.H.	95	92	90	87	84	82	80	78	76	72	67	63	60	56	50	43	37	32	27	22	16	10
	EMC	21½	19½	18	16½	15½	14½	13½	13	12½	11½	10½	10	9	8½	7½	6½	6	5	4½	4	3	2
60	R.H.	95	92	90	88	85	83	81	79	77	73	69	65	61	58	52	45	40	35	30	25	20	14
	EMC	21½	19	17½	16½	15½	14½	13½	13	12½	11½	10½	10	9	8½	7½	7	6	5½	4½	4	3½	2½
65	R.H.	95	93	91	88	86	84	82	80	78	74	70	66	63	60	53	47	42	37	32	28	22	17
	EMC	21	18½	17	16	15	14	13½	13	12½	11½	10½	10	9	8½	7½	7	6	5½	5	4	3½	3
70	R.H.	96	93	91	88	86	84	83	81	79	75	71	68	65	61	55	50	44	40	35	31	25	20
	EMC	20½	18½	17	15½	15	14	13½	13	12	11	10½	9½	9	8½	7½	7	6	5½	5	4½	3½	3
75	R.H.	96	93	91	89	87	85	83	82	80	76	72	69	66	63	57	51	46	41	38	33	28	22
	EMC	20	18	16½	15½	14½	14	13	12½	12	11	10	9½	9	8½	7½	6½	6	5½	5	4½	3½	3
80	R.H.	97	93	91	89	87	86	84	82	81	77	74	70	67	64	59	53	48	43	40	36	30	25
	EMC	19½	17½	16	15	14½	13½	13	12½	12	11	10	9½	8½	8	7½	6½	6	5½	5	4½	4	3½
85	R.H.	97	93	91	90	88	86	84	82	81	78	74	71	68	65	60	54	49	45	41	38	32	27
	EMC	19½	17	16	15	14	13½	12½	12	11½	10½	10	9	8½	8	7	6½	6	5½	5	4½	4	3½

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[1] Relative humidity values on upper lines with heavy type; equilibrium moisture content values on lower lines with light type.

Table 8.--Amount to raise temperature for various EMC values in heated room drying

EMC value desired	Degrees above average outdoor temperature at--		
	65 percent relative humidity	75 percent relative humidity	85 percent relative humidity
Percent	°C.	°C.	°C.
7	10	12	-------------
8	6-1/2	9	12
9	4-1/2	6	9
10	2-1/2	5	7-1/2
11	1	3	6
12	-------------	2	5
13	-------------	1	3

Table 9.--Kiln schedule "A" for timbers that must not darken or that warp badly, but do not check[1]

Moisture content at start of step	Dry-bulb temperature	Wet-bulb temperature	Relative humidity (approx.)
Percent	°C.	°C.	Percent
Green	35	30.5	70
60	35	28.5	60
40	38	29	50
30	43.5	31.5	40
20	48.5	34	35
15	60	40.5	30

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[1] British Forest Products Research Laboratory Leaflet No. 42 (Appendix A).

Table 10.--Low-temperature schedules "B," "C," and "D," for timbers that check[1]

Moisture content at start of step	Dry-bulb temperature	Wet-bulb temperature	Relative humidity (approx.)
Percent	°C.	°C.	Percent
	SCHEDULE B		
Green	40.5	38	85
40	40.5	37	80
30	43.5	39	75
25	46	40.5	70
20	54.5	46	60
15	60	47.5	50
	SCHEDULE C		
Green	40.5	38	85
60	40.5	37	80
40	43.5	39	75
35	43.5	38	70
30	46	39.5	65
25	51.5	43	60
20	60	47.5	50
15	65.5	49	40
	SCHEDULE D		
Green	40.5	38	85
60	40.5	37	80
40	40.5	35.5	70
35	43.5	36	60
30	46	36	50
25	51.5	38	40
20	60	40.5	30
15	65.5	44.5	30

[1] British Forest Products Research Laboratory Leaflet No. 42 (Appendix A).

Table 11.--Kiln schedules "E," "F," and "G," mostly for moderate-drying hardwoods[1]

Moisture content at start of step	Dry-bulb temperature	Wet-bulb temperature	Relative humidity (approx.)
Percent	°C.	°C.	Percent
SCHEDULE E			
Green	48.5	46	85
60	48.5	45	80
40	51.5	46.5	75
30	54.5	47	65
25	60	49	55
20	68	53	45
15	76.5	58	40
SCHEDULE F			
Green	48.5	44	75
60	48.5	43	70
40	51.5	43	60
30	54.5	43	50
25	60	46	45
20	68	51	40
15	76.5	58	40
SCHEDULE G			
Green	48.5	46	85
60	48.5	45	80
40	54.5	50.5	80
30	60	55	75
25	71	63.5	70
20	76.5	64	55
15	82	62.5	40

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[1] British Forest Products Research Laboratory Leaflet No. 42 (Appendix A).

Table 12. --Kiln schedules "H," and "J," for easy drying hardwoods and some softwoods[1]

Moisture content at start of step	Dry-bulb temperature	Wet-bulb temperature	Relative humidity (approx.)
Percent	°C.	°C.	Percent
SCHEDULE H			
Green	57	53	80
50	57	52	75
40	60	52	65
30	65.5	54	55
20	76.5	58	40
SCHEDULE J			
Green	57	50.5	70
50	57	48	60
40	60	67.5	50
30	65.5	49	40
20	76.5	53	30

[1] British Forest Products Research Laboratory Leaflet No. 42 (Appendix A).

Table 13. --Kiln schedules "K," "L," and "M" for easy drying softwoods[1]

Moisture content at start of step	Dry-bulb temperature	Wet-bulb temperature	Relative humidity (approx.)
Percent	°C.	°C.	Percent
SCHEDULE K			
Green	71	66	80
50	76.5	68.5	70
30	82	70.5	60
20	88	67.5	40
SCHEDULE L			
Green	82	74	70
40	93.5	72	40
SCHEDULE M			
Green	93.5	84.5	70
50	99	81.5	50

[1] British Forest Products Research Laboratory Leaflet No. 42 (Appendix A).